Afton Halloran
Roberto Flore
Paul Vantomme
Nanna Roos
Editors

Edible Insects in Sustainable Food Systems

Springer

Edible Insects in Sustainable Food Systems

Afton Halloran • Roberto Flore
Paul Vantomme • Nanna Roos
Editors

Edible Insects in Sustainable Food Systems

Springer

Editors
Afton Halloran
Department of Nutrition, Exercise and Sports
University of Copenhagen
Frederiksberg C, Denmark

Roberto Flore
Nordic Food Lab
Department of Food Science
University of Copenhagen
Frederiksberg C, Denmark

Paul Vantomme
FAO
United Nations Food and Agriculture Organization
Rome, Italy

Nanna Roos
Department of Nutrition, Exercise and Sports
University of Copenhagen
Frederiksberg C, Denmark

ISBN 978-3-319-74010-2 ISBN 978-3-319-74011-9 (eBook)
https://doi.org/10.1007/978-3-319-74011-9

Library of Congress Control Number: 2018938384

Photo credit: Afton Halloran
Caption: Bee larvae taco by Roberto Flore

Printed on acid-free paper

This Springer imprint is published by the registered company Springer International Publishing AG part of Springer Nature.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This book is dedicated to Dr. Alan Yen, who sadly passed away on March 20, 2017. His dedication and passion for edible insects and conservation was an inspiration for many.

Preface

Crickets, locusts, grasshoppers, mealworms, black soldier flies and termites – these are just a handful of the protagonists that you will meet in this book, selected because of their environmental, social, economic and cultural importance.

Wild insects have been a part of the diets in human cultures around the world, and to date, more than 2100 species have been recorded as 'edible'. However, over the past few years, edible insects have moved from belonging to a large and diverse group of traditional foods with little attention from the stakeholders in the formal food system, to being claimed as the 'future of food'.

The vast diversity in the use of insects for food and feed is reflected in this book by the wide range of inputs from authors from all over the world, documenting the fascinating variation in uses of insects across cultures. The emergence of insect farming has also sparked a new form of production which has shifted many of these countries to move from wild harvesting to farming insects.

As can be seen from the contributions from the chapter authors, there are varying opinions of the role of edible insects in sustainable foods systems. Thus, the aim of this book is to present and clarify a wide spectrum of cases, opinions and research on the topic of edible insects and their relationship to sustainable food systems. Inputs were provided by a wide range of authors from the public, academic, governmental and private sectors, with the belief that all those views may help clarifying more comprehensively the role in insects in more sustainable food systems.

The internationality of this textbook is shown by chapters from authors of over 20 nations and four continents are represented. Moreover, many disciplines are covered by this book, such as entomology, agricultural economics, human nutrition, environmental science, fisheries and animal science, sociology and anthropology, reflecting the interdisciplinary efforts that have been made by the editors to describe sustainable food systems globally.

We believe that this book will be useful for students, researchers, farmers, food and feed processors, decision- and policy makers, investors, NGOs/international organizations and entrepreneurs in the food sector.

Copenhagen, Denmark — Dr. Afton Halloran
Copenhagen, Denmark — Roberto Flore
Rome, Italy — Paul Vantomme
Copenhagen, Denmark — Dr. Nanna Roos

Acknowledgements

The editors would like to say a special thanks to Christopher Münke-Svendsen and Dana Wilderspin for their inputs to the book.

Introduction

The release of the Food and Agriculture Organization of the United Nation's publication *Edible Insects: Future Prospects for Food and Feed Security* in May 2013 accelerated attention to the past, present and future uses of insects in human diets and as animal feed ingredients. Researchers, entrepreneurs and practitioners around the world were roused to action by this traditional and yet novel utilization of insects. In recent years, activities to explore and exploit insects for food and feed have resulted in an explosion in the number of academic publications on the topic, accompanied by a great deal of new companies that have popped up in most corners of the world. From the academic world, studies on the role of insects in food systems cross disciplinary boundaries and bring together scientists from natural and social science as well as the humanities to document the past and explore the future potential of this group of organisms that up until now have escaped the globalization of food systems.

The words 'sustainable' and 'sustainability' have often accompanied the terms 'entomophagy' – the consumption of insects – and 'edible insects'. While a global concern about the sustainable utilization of resources was born at the Rio Earth Summit over 25 years ago, there have been few major renewals in food systems that could bring hope for more sustainable food production up until now. The FAO publication ignited this hope by pointing out the overlooked potentials of insects. Consequentially, many academics and entrepreneurs have been inspired to explore how this potential can be unfolded, begging the question: *Why, how and for whom can farming or gathering insects as food and animal feed be a sustainable part of food systems, locally and in a globalized world?*

What is a sustainable food system? A food system is considered sustainable when it delivers food security and nutrition for all in a way that economic, social and environmental sustainability is not compromised for future generations.[1] The sustainability of food systems can be interpreted in a variety of ways, depending heavily on context, culture, economic scale and geographical location. To explore the state of turning hope into reality, we have gathered cross-cutting cases and studies

[1] As defined by the High Level Panel of Experts on Food Security and Nutrition (HLPE).

from across the world related to the environment, people, production, infrastructures and institutions involved in shaping the role of insects in food systems as well as the current and intended impacts of these activities on livelihoods and environment.

The sustainability of our food systems is already challenged and will be further challenged in the future as the demand to feed the growing world population continues. At the same time, increased consumption of foods of animal origin, urbanization, climate change and degradation of land, water and ecological systems and loss of biodiversity challenge natural resources and place further constraints on food production. Insects are not a silver bullet to solving all global challenges. Nonetheless, our growing understanding of the potential of insects can be a part of the solution to transforming our food systems to become more sustainable overall.

While global dietary transition raises the average consumption of meat, fish, milk and other animal-source foods (ASF) (IFPRI 2015), malnutrition persists as a significant public health concern causing millions of deaths in children in low- and middle-income countries, particularly in Asia and Africa. Poor quality of the everyday diet is a key problem in the populations burdened by undernutrition, and improving the access to a nutritious diet, in particular, access to ASF in poor households, is critical to secure good nutrition for all (IFPRI 2015). ASF have been shown to improve dietary quality, micronutrient status, growth and cognitive function in children (Dror and Allen 2011). However, ASF are often expensive and therefore not accessible for the households in need. ASF production also has a large environmental footprint, and expanding traditional livestock production systems to meet the nutritional needs of the populations may inhibit the environmental sustainability of the food systems of the future. In this context, insect farming has emerged as a promising opportunity either through providing nutritious ASF for direct consumption (Halloran et al. 2016) or through producing high-quality protein for animal feed with less environmental impact (van Huis 2013).

A segment of modern consumers is becoming increasingly aware of the consequences associated with the production of the meat they consume, generating concerns over animal welfare and the environmental impact of livestock production. A wide range of commercial insect products have emerged over the past years, taking different shapes and forms such as energy bars, burgers, flours and snack foods. While some consumers may not wish to consume these products, willingness to consume the meat or eggs derived from an animal fed a diet consisting of insects may be higher. However, consumer preferences and willingness to pay for insect products depend on many factors such as geographical location, consumers' perceptions of the product attributes. Further, insects cannot be lumped together into one category. In fact, each insect has its own specific processing and preparation requirements (Evans et al. 2017). Edible insects have also been an important part of not only food culture in many parts of the world, but also storytelling, song, folklore and spirituality, representing the traditions that make up intangible heritage for humanity (Costa-Neto 2015; Kelemu et al. 2015). As a result, recipes have reflected this profound knowledge and relationship that human beings have developed over millennia (Evans et al. 2015). At the same time, researchers, food entrepreneurs and chefs alike are developing new ways to use insects as a food ingredient.

Legislation and regulations of insect farming and insect value chains are unfolding in many countries. The production, processing, consumption, trade and use of edible insects concern a variety of regulatory bodies, from food safety and conservation authorities to ministries of environment, health and agriculture. The traditional collection and utilization of edible insects have largely been part of informal unregulated food systems. However, the transition from harvesting insects to farming them also brings out questions concerning the regulations of the formalized food systems (Yen 2015). Edible insect species, in most cases, have simply been off the radar of decision-makers as they are often a part of informal trade or are considered as unimportant (Belluco et al. 2017). As a result, there is a lack of institutional governance surrounding the consumption and production of edible insects.

As we pave the way for a more sustainable future for our food systems, we must continue to address the long-term challenges and knowledge gaps. Thus, an enhanced understanding of the value chain, legislation and regulations, impacts on rural economy, and possible improvements in production methods and techniques is required. Moreover, the investigation of the linkages between agriculture and nutrition is essential for the creation of more socially, environmentally, economically and culturally sustainable food systems.

This book presents a state of the art of a rapidly developing field of documenting, exploring and developing insects in local and global food systems. It is made up of eight different sections which address key topics related to how insects can contribute to sustainable food systems. Part I introduces the basic principles of entomology, the science of insects. In Part II, the role of edible insects in culture is addressed. Part III touches on aspects of nutrition and health. Part IV discusses the gastronomic applications of insects and their uses in the future. In Part V, the environmental impacts associated with insect production as well as conservation and ethics are analyzed. Part VI deliberates various aspects of insects as animal feed ingredients. The multiple aspects of consumer preferences and acceptability are investigated in Part VII. The final section, Part VIII, scrutinizes the policy and legislation which affects insects for food and feed in a variety of regions around the world.

References

Belluco S, Halloran A, Ricci A (2017) New protein sources and food legislation: the case of edible insects and EU law. Food Sec 9:803–814. doi: https://doi.org/10.1007/s12571-017-0704-0

Costa-Neto EM (2015) Anthropo-entomophagy in Latin America: an overview of the importance of edible insects to local communities. J Insect Food Feed 1:17–23. doi: https://doi.org/10.3920/JIFF2014.0015

Dror DK, Allen LH (2011) The importance of milk and other animal-source foods for children in low-income countries. Food Nutr Bull 32:227–243. doi: https://doi.org/10.1177/156482651103200307

Evans J, Alemu MH, Flore R, et al (2015) Entomophagy: an evolving terminology in need of review. J Insect Food Feed 1:293–305. doi: https://doi.org/10.3920/JIFF2015.0074

Evans J, Flore R, Frøst MB (2017) On eating insects: essays, stories and recipes, 1st edn. Phaidon Press, London/New York

Halloran A, Roos N, Eilenberg J, et al (2016) Life cycle assessment of edible insects for food protein: a review. Agron Sustain Dev 36:57 doi: https://doi.org/10.1007/s13593-016-0392-8

IFPRI (2015) Global nutrition report actions and accountability to advance nutrition & sustainable development. International Food Policy Research Institute, Washington, DC

Kelemu S, Niassy S, Torto B, et al (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insect Food Feed 1:103–119. doi: https://doi.org/10.3920/JIFF2014.0016

van Huis A (2013) Potential of insects as food and feed in assuring food security. Anal Rev Entomol 58:563–583

Yen AL (2015) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insect Food Feed 1:33–55. doi: https://doi.org/10.3920/JIFF2014.0017

Contents

Part IV Gastronomy

Part V Environmental Impacts, Conservation and Future Challenges

Part VI Insects as Animal Feed

Part VII Consumer Preferences and Acceptability

Part VIII Legislation and Policy on the Use of Insects as Food and Feed

Part I
Introduction to Insects

Insects: Key Biological Features

Jørgen Eilenberg and Joop J. A. van Loon

Abstract In this chapter, we present a brief introduction to the biology of insects, the arthropod class Insecta. We describe diversity of insects and how their bodies are structured. We also provide information about key biological features, starting with the insect exoskeleton, its structure and function. Furthermore, the insect gut and its functions are explained as well as insect growth and development. We end by describing considerations and methods for insect collecting and sampling in the field to initiate and sustain insect rearing.

1 What Are Insects?

A basic definition of insects is that they are a class of invertebrate animals (Insecta) that have an exoskeleton and six legs. At present more than 1 million insect species have been described making insects the largest class of organisms on Earth; over 75% of all known animal species are insects. Insects can be found in all terrestrial eco-systems in the world and in all climatic zones (tropical rainforest, arid deserts, boreal forests and meadows, arctic environment *etc*) (Gullan et al., 2014). They are also found in lakes and in coastal aquatic environments. In terrestrial ecosystems insects make up a large portion of the biomass and fulfil several crucial important 'ecosystem services', major examples of which are biological control, pollination of flowers and bioconversion of decaying organic material.

Insect body structure and outer appearance are highly diverse in size, shape and colour, yet the body of all adult insects is composed out of three major parts: head, thorax and abdomen (Fig. 1) (Chapman et al., 2013). The head bears the antennae,

J. Eilenberg (✉)
Department of Plant and Environmental Sciences, University of Copenhagen, Frederiksberg C, Denmark
e-mail: jei@plen.ku.dk

J. J. A. van Loon
Laboratory of Entomology, Wageningen University and Research, Wageningen, The Netherlands

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_1

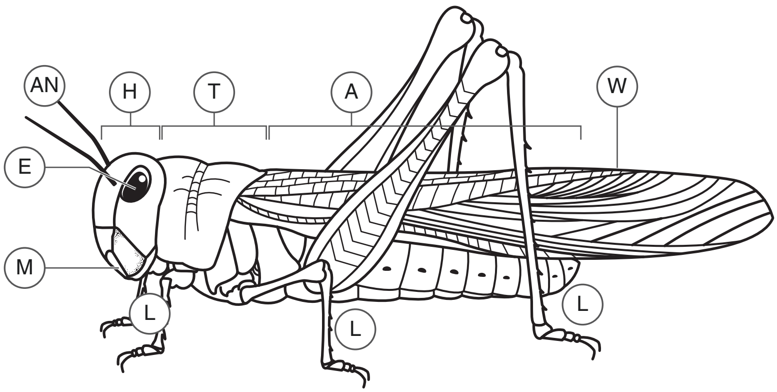


Fig. 1 The three major body parts of a locust as a model for insects: head (H), thorax (T) and abdomen (A). Attached to the head are the antennae (AN), eyes (E) and mouthparts (M). Attached to the thorax and covering its dorsal side are the wings (W) and on the ventral-lateral side the legs (L)

Table 1 The most important orders of insects of relevance as food and feed (Van Huis and Tomberlin, 2017)

Insect order	Development	Life stages	Examples
Orthoptera	Hemimetabolic	Eggs, nymphs, adults	Crickets, locusts, grasshoppers
Hemiptera	Hemimetabolic	Eggs, nymphs, adults	Aphids, true bugs
Blattodea	Hemimetabolic	Eggs, nymphs, adults	Termites, cockroaches
Diptera	Holometabolic	Eggs, larvae, pupae, adults	Black soldier fly, house fly
Lepidoptera	Holometabolic	Eggs, larvae, pupae, adults	Mealmoth, mopane moth
Coleoptera	Holometabolic	Eggs, larvae, pupae, adults	Mealworms, palm weevils
Hymenoptera	Holometabolic	Eggs, larvae, pupae, adults	Ants, honey bees

eyes and mouthparts. The antennae are used for smelling (olfaction), taste (gustation) and touch (mechanoreception). The mouthparts are highly diversified as are the diets of insects but two basic types can be distinguished: biting-chewing or piercing-sucking mouthparts, adapted for ingestion of solid and fluid food respectively. The mouthparts are populated with sensilla for smelling, tasting and touch. The thorax has three segments, each bearing one pair of jointed legs that bear taste and touch sensilla. Usually, adult insects have two pairs of wings attached to the second and third thoracal segments, but adult insects in the order of Diptera (flies and mosquitoes) have a rudimentary second wing pair, the halteres. Also, in some orders, adult insects are wingless. Evolution of wings is one of the main reasons for the abundance of insects, because they allow fast dispersal and migration when environmental circumstances are unfavourable.

The class Insecta consists of almost 25 different orders. Among well-known insect orders are for example beetles (Coleoptera, *ca.* 370,000 described species); butterflies and moths (Lepidoptera, *ca.* 200,000 species); true flies (Diptera, *ca.* 122,000 species); ants, bees and wasps (Hymenoptera: *ca* 150,000 species); crickets, grasshoppers and locusts (Orthoptera, *ca*. 22,500 species). In Table 1 insect orders of most significance for use as food and feed are shown.

In this introductory chapter we discuss a number of key biological features of insects: their exoskeleton, growth and development, poikilothermy and their diets and digestive physiology.

2 The Insect Exoskeleton

The entire insect body is lined with a cuticular integument ('skin') as a barrier between the body interior and the environment. The integument is composed of the epidermis separated from the haemocoel by a basement membrane and from the outside by the cuticle. The integument serves many functions in insect biology.

The integument determines the shape and form of insects, because its cuticle functions as an exoskeleton. Muscles attach to the exoskeleton and its internal extensions (apodemes) hence its role in locomotion. In addition, it forms a protective barrier, preventing the entrance of microorganisms and the loss of water. Water loss poses a big risk for these relatively small terrestrial animals, which have an unfavourable surface to volume ratio. The cuticle also protects against attack by predators and parasitoids (Box 1). Cuticle occurs not only on the outside but is also present in the inside: foregut, (stomodaeum), hindgut (proctodaeum), the apodemes and the tracheal system, the respiratory system of insects that relies on diffusion of oxygen and carbon dioxide, a mechanism very different from the blood vessel system and oxygen-binding blood pigments in higher animals.

In addition to its roles as skin and skeleton, typical structures of the integument are associated with a large number of secondary functions. Perception of information

Box 1 Functions of the Insect Exoskeleton

Primary functions

- Muscle attachment and articulation
  - Locomotion: legs, wings
  - Food uptake: mouthparts
- Protection against:
  - Water loss
  - Microorganisms
  - Natural enemies: predators, parasitoids

Secondary functions

- Reproductive structures
- Sensory structures (sensilla, setae)
- Pigmentation (warning colors, mimicry)
- Excretion of chemicals (infochemicals, defensive substances)

from the environment is mediated by sensory organs *e.g.* compound eyes, antennae, and sensilla. The integument is also involved in communication between individuals and between species. Exchange of (mostly chemical) information may also take place by specific chemical products from dermal glands. These products have roles in defense, protection (resin, wax, mucus) or in communication (*e.g.* pheromones).

Reproduction requires special cuticular structures as well. External genitalia are used during mating behaviour in sexual reproduction. These structures can be so complicated and variable that they are used for identification of insect species. In a number of species other cuticular structures are also associated with reproduction. Sound production is one of the possibilities for communication between sexes. Some species have developed special structures to produce and perceive sounds, *e.g.* in crickets (Orthoptera). Sound may also act as deterrent, e.g. warning in territory defence, or used for aggregation.

2.1 Cuticle Microstructure

Despite variations in form and functions, integuments are histologically speaking rather simple. They are composed of only one type of tissue, the epidermis, which secretes the cuticle to the outside and is separated from the haemocoel, the body cavity containing the haemolymph ('blood'), by a *ca*. 0.5 μm thick layer of mucopolysaccharides, the basement membrane. The function of the epidermis is sustained by a number of scattered dermal gland cells (Verson glands) and by oenocytes. The glands are believed to secrete cement on the surface of the new cuticle after a moult (see **2.**) Oenocytes are responsible for synthesis of cuticular lipids, particularly hydrocarbons (waxes). Hydrocarbons comprise the thin apolar outer surface of insect cuticles. The epidermis is a secretory epithelium, which can be inferred from the large number of microvilli at the apical pole of the cells, indicative of active secretion into the cuticular compartment, the space between the epicuticle and the epidermis. Undifferentiated cuticles consist of two layers, the thin (less than 4 μm) epicuticle, which covers the complete outside surface of the body and the procuticle, which can be up to 200 μm in thickness (Fig. 2). The epicuticle can be as thin as 15 nm and is composed of three layers. The inner epicuticle layer, probably a lipoprotein, the outer epicuticle and the wax layer, which coats the outer surface. The wax layer is extremely important, because it restricts water loss and thereby prevents desiccation. In some species the wax is stabi1ised by the presence of cement, a kind of varnish.

The procuticle is composed of ~ 50% protein and ~ 50% chitin and has a multilaminate character. In larval stages of many insect species the procuticle does not differentiate, but in other cuticles it is differentiated into the outer exocuticle and the inner endocuticle. The exocuticle is hard and mostly dark, the result of sclerotisation (tanning). This process does not occur along the whole surface, but in patches, which explains the stiffness of certain parts of the cuticle. The membraneous parts of the cuticle are not sclerotised, allowing for flexibility. During moulting (see **2.**)

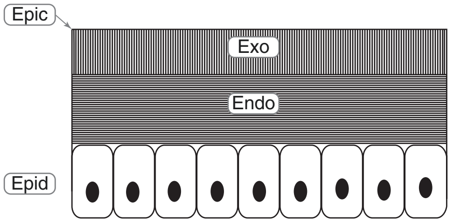


Fig. 2 Simplified insect integument, showing the different cuticular layers and cells. Epic = epicuticle, Exo = exocuticle, Endo = endocuticle, Epid = epidermal epithelium. Each layer is subdivided into sublayers (Drawing was based on wikipedia, CC BY-SA 3.0, Source: https://commons.wikimedia.org/w/index.php?curid=34188028)

the endocuticle is digested and its compounds recycled for the production of the new cuticle. The epi- and exocuticle are not reused and shed during moulting.

Since formation of cuticle occurs from inside out, the outermost layers will be deprived of renewal or restoration if materials cannot be transported across the cuticle to the outside. This is particularly true for the outer wax layer, which plays a decisive role in regulation of evaporation and water balance in insects. Damage of this layer would rapidly be lethal. However, transport of wax and other materials takes place through narrow (0.15–1.0 μm*)* pore canals. It is believed that the epicuticular lipid is continuous with lipids from inside through the pore canals of the procuticle, which branches into tiny wax filaments in the epicuticle. The structural organisation of wax in the outer layer and the water and lipid composition of the pore canals may be of prime importance for the regulation of evaporation, but our understanding of these processes are still far from complete.

2.2 Cuticle Chemistry

Protein and chitin are the main components of cuticles. Chitin is a polymer of N-acetylglucosamine, linked by 1–4 β-glycosidic bonds (Fig. 3). Chitin is synthesized within the epidermal cells, but the chitin polymers co-crystallise outside the cell membrane by hydrogen bonding into highly ordered longitudinally oriented microfibrils, 2.5–5.0 nm in diameter. The chitin crystallites are surrounded by protein. The microfibrils are parallel oriented into layers (lamellae). The orientation of the microfibrils differs between different lamellae. Formation of lamellae does not only occur during moulting but continues during the intermoult and during the first few days of adult life. Deposition of chitinous lamellae occurs in daily layers. Up to 100 cuticular proteins have been identified by electrophoresis. Different proteins occur in different regions of the cuticle or different developmental stages. Experiments have demonstrated that some proteins are present only in larval, pupal or adult cuticles, whereas others are present in cuticles of all stages. Little is known about the exact contribution of proteins to the organisation and mechanical

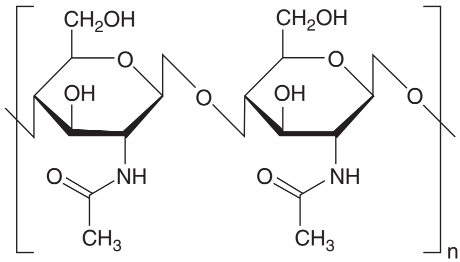


Fig. 3 Structure of chitin, a major component of insect cuticle (Source: https://commons.wikimedia.org/wiki/)

properties of cuticles, except for a rubber-like protein called resilin, which is very abundant in the membraneous wing-base and other articulations (joints) and enhances the elastic properties of the wing/thorax resonance system.

An important process for the structural organisation of the cuticle is sclerotisation or tanning, which occurs directly after shedding of the old cuticle. Sclerotisation is the enzyme-catalysed incorporation of low molecular weight phenolic material into the cuticle, resulting into an increase in stiffness and resistance to digestion and degradation. During this process the cuticle will often become darker in colour, the water content decreases and the phenols become covalently linked to protein and chitin. Sclerotising agents are derived from the amino acid tyrosine, which is enzymatically converted to DOPA (L-3,4-dihydroxyphenylalanine), dopamine, N-acetyldopamine and acetyldopamine quinone. The quinones are covalently cross-linked between reactive side-groups of cuticular proteins or between protein and chitin by an enzymatic process which renders these compounds very resistant to digestion. In a number of insects these sclerotising agents accumulate in the haemolymph before the moult and are transferred to those regions of the cuticle that become sclerotised. During this process the cuticle often becomes darker, which is due to the formation of melanin, also a polymerisation product of N-acetyldopamine. Browning and blackening of wounded insects or occurring during processing of insects is caused by the action of enzymes involved in tanning.

3 Insect Growth and Development

The exoskeleton limits growth and must therefore be renewed regularly: insects grow step-wise from one instar to the next. At the end of each instar a moult occurs, a process which starts by retraction of the epidermis from the old cuticle (apolysis) and ends with shedding it (ecdysis), after the production of a new cuticle with an increased surface area. Sometimes the old cuticle is not shed and the next stage is surrounded by two cuticles: pharate stage. An example is the pupal stage of higher Diptera. The old larval cuticle becomes the puparium, which is sclerotised and surrounds the actual pupal cuticle. Although moults differ qualitatively (larval-larval, larval-pupal and pupal-adult moults), the moulting process takes place in a very similar way. Moulting results in morphological changes which may dramatically affect the appearance of the different stages. Thus moults are accompanied by quantitative as well as qualitative changes in cuticle formation. In some orders qualitative changes are limited. Adults and larvae only differ in size, not in shape, *e.g.* in the insect order Ametabola (includes silverfish). In other orders, morphological changes during development are limited to increase in body size and the gradual full development of the wings ending in the adult phase. Young instars (named nymphs) and adults look quite similar, these insect orders are together named Hemimetabola (Fig. 4). In more advanced insect orders, the external morphology of larvae and adults may be completely different. Larval and adult stages are separated by a pupal stage, in which complete metamorphosis takes place, the transformation between the larval and adult life stages; these insect orders are named: Holometabola (Fig. 4). Many tissues remain undifferentiated during larval development (which typically include four to six larval instars; in the beetle family Tenebrionidae there may up to 20 instars) of holometabolous insects. Future adult organs are present as internal buds of embryonic tissue, known as imaginal discs.

4 The Insect Gut

Different insect species consume very different food items, either solid or liquid: fresh leaves, stems, flowers or fruits; plant sap; pollen; dry wood; other arthropods; fresh vertebrate blood; fungi; decaying organic material. Species consuming solid diets have biting-chewing mouthparts (mandibles, analogous to the jaws of vertebrates), those consuming liquid diets have piercing-sucking stylet-type mouthparts that enclose two thin canals (diameters of one to a few micrometres) through which saliva is secreted and food ingested. After passing the mouthparts, food enters the insect digestive system or gut, which shows a wide diversity in morphology and function depending on the diet consumed. It is important to know the biological mechanisms of food uptake and digestion in the gut of any insect species considered for rearing and production.

The gut of insects has three major parts: foregut, midgut, and hindgut. Figure 5 exhibits the gut system in crickets. A posterior part of the foregut, the proventriculus, has a muscular wall, grinds the food and regulates food passage into the midgut. A range of glands producing saliva can be associated with the foregut. The midgut (ventriculus, Fig. 5) is a very important part of the gut, and enzymatic digestion occurs predominantly in this part. Cells in the midgut cover the inner surface and they are a part of a dynamic system: gut epithelial cells grow, differentiate and proliferate as part of insect growth and development. Digestive enzymes, such as proteases, lipases, and amylases are produced by the epithelial cells and secreted into the midgut, resulting in breakdown of food proteins, lipids and polymeric carbohydrates (*e.g.* starch) into small molecules: peptides and amino acids, fatty acids and glucose, fructose and other monomeric sugars respectively. Inside the insect

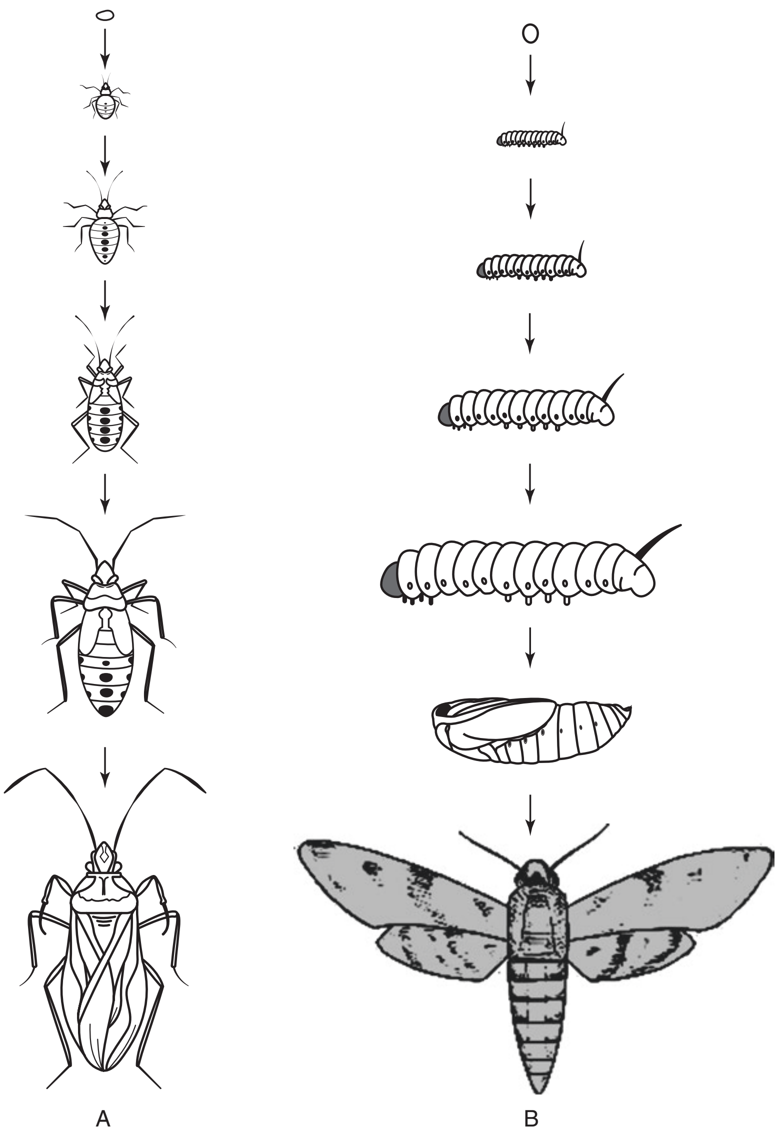


Fig. 4 The two basic types of insect development. (**a**) Hemimetabola (egg, four nymphal stages, and adult). (**b**) Holometabola (egg, four larval stages, pupae, and adult)

midgut the peritrophic membrane is found. This tubule-shaped membrane has several important functions. It protects the midgut epithelium against damage; it acts as an ultrafilter preventing harmful microbes to reach the epithelium, and it subdivides the midgut into two concentric compartments which allows counterflow

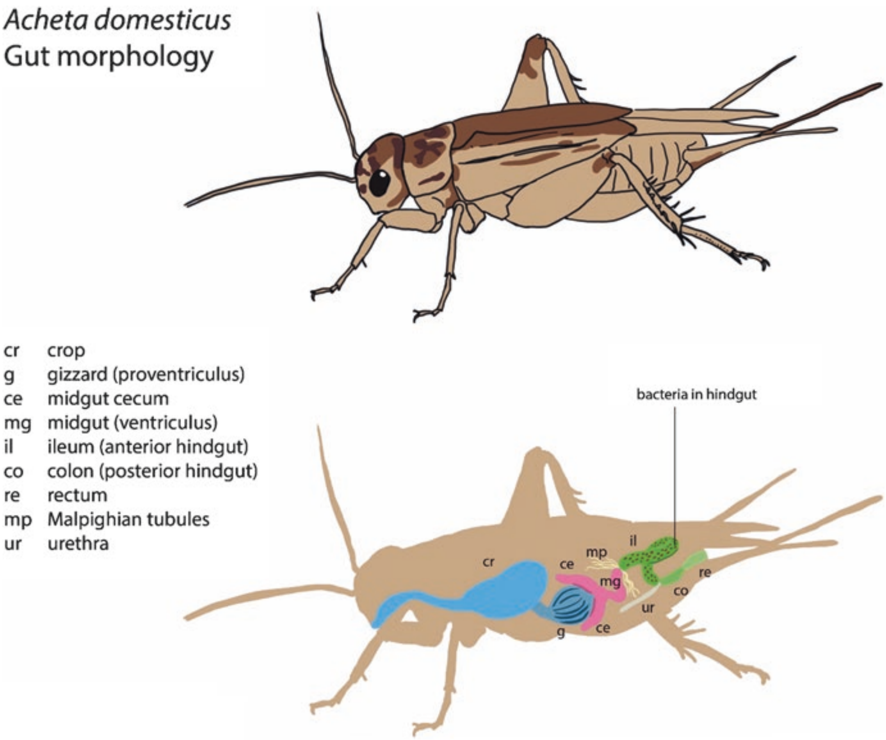


Fig. 5 Gut morphology of the House cricket *Acheta domesticus* L (Drawing by Stijn Schreven)

of digestive fluids. Of particular importance for digestion of plant cell walls are the alkaline conditions (pH 9–12) in the insect midgut. Gut pH varies between insect species, depending on their natural food source and pH may even be low in certain Dipteran species. Microorganisms (often bacteria, but also fungi and protists) are important as gut symbionts, which can be intracellular or extracellular. While it appears that predatory insects do not harbour symbionts, many herbivores and detritivores seem to host such symbiotic microorganisms, which assist in digestion. Insects feeding on dry wood, *e.g.* termites, may harbour a high diversity of symbionts. As outgrowths from the midgut, Malpighian tubules (Fig. 5) assist in excretion of filtrates into insect haemolymph. While the midgut is essential for food digestion in insects, it is also the entry site for insect pathogenic viruses, bacteria and microsporidia. These pathogens can bind to the gut epithelial cells and penetrate into the haemolymph. The hindgut consists of an anterior part (ileum) and a posterior part (rectum). Undigested food and waste products of metabolism, *e.g.* uric acid, are excreted through the rectum as faecal matter.

5 Establishing an Insect Colony: Field Collection of Live Insects

To start an insect colony for continuous rearing, specimens can be obtained from established colonies or can be collected in the field. Insects from established colonies are often inbred for many generations and adapted to the specific circumstances under which they have been kept: a particular diet, light type and intensity, temperature and humidity. The history and exact rearing circumstances of established colonies are often unknown. Field-collected insects do not have these limitations but care must be taken to (1) start a colony with at least several hundreds of individuals to ascertain sufficient genetic variation in the founder population; (2) to discard individuals that show symptoms of disease (see **6**.) In order to collect insects from nature it is essential know the insect's biology: which instars should be sampled? How do the different instars look like? Where do the larval instar or adults occur? Which handbooks should be used and/or which knowledge and training are necessary prerequisites? In case of a plant-feeding species, *e.g.* two-spotted field crickets (*Gryllus bimaculatus* Geer): on which host plant species does it feed? It is also important to know the annual life cycle of the insect to be collected or sampled to learn during which periods the different life stages (eggs, nymphs/larvae, pupae, and adults) are present on a locality. For example, aphids and true bugs (order Hemiptera) can during summer be sampled directly on their host plants, where both nymphs and adults are located. Some aphid species will during autumn move to trees for winter hibernation. For insects like root flies, eggs can be sampled on the soil surface, near host plants, whereas larvae and pupae live in the soil. The adult flies can be sampled with a net, for example when visiting flowers. Several larval beetle species feed on roots and lead a subterranean life, while adults are found on vegetation or flying around. Different sampling methods must thus be employed for larval and adult stage of such beetles.

In order to collect insects from the field, several methods are available (Table 2). Concerning flying insects, there are basically two methods: either they can be collected by using a net or they can be attracted to light, pheromones or a food source. For many insect species, a particular sampling method does only allow collection of either immature stages or adults. The standard tools to be used for field work include hand lenses with about 10X magnification, tweezers, scissors, forceps, plastic bags or boxes, trowel (for digging in soil). There are protocols for collecting insects in order to ensure that collecting takes place properly and especially that no one collects or samples more insects than needed for studies. Any collector must be aware of protected and endangered insect species which must not be collected at all. Several species of insects in Europe and elsewhere are protected and it is not allowed to collect them. For Europe, information about protected insect species can be found on this website: (http://ec.europa.eu/environment/nature/conservation/species/habitats_dir_en.htm). Each collector should before sampling carefully check such information, which may even be country specific. For example, red forest ant *Formica rufa,* is protected in Germany, while not in Denmark.

Table 2 Different commonly used sampling methods to collect insects

Sampling method to collect live insects	Comments
Sweep net	To collect flying/swarming insects like winged termites and for collecting insects on vegetation
Hand picking	To collect leaf-feeding or plant-sucking insects, *e.g.* larvae of butterflies and moths or true bugs respectively
Soil digging	To collect larvae, pupae or adults living in the soil by using a trowel or equipment for obtaining more precise soil samples
Light traps	To attract many types of flying insects to a light source associated with a trap during the night
Pitfall traps	To collect soil-dwelling insects like carabid beetles. A detergent can be added to the trap
Pheromone traps	Female pheromone can attract males of *e.g.* moth species to traps

In relation to insects as food, the habit of foraging for insects to bring home for consumption poses additional challenges. The collector must first of all be well aware of the precise characteristics of the insect species to be sampled to avoid mixing up with other species that may well be inedible. Such indigenous knowledge is not necessarily directly connected to scientific taxonomy, since the way to name and determine insects collected for food has been carried over orally between successive generations.

Since the sampling will remove insects from the ecosystem the collector must have a good knowledge of population biology and be capable to judge the number of insects that can be harvested at a given time without causing extinction of the local insect population. Such foraging experience is well developed for insects in many parts of the world, where harvesting insects from nature has been a part of the culture, but is almost totally absent in for example Europe and other places, where there is no tradition of collecting insects as food (Van Huis and Tomberlin 2017).

6 Insect Rearing: Purposes, Scales and Cautions

Many insect species from almost all insect orders are being reared for research purposes. However, the large majority of the *ca.* 1 million described insect species have never been reared, either because nobody tried or because attempts failed. To rear insects, entomological knowledge and experience is vital, as are adequate food and housing. Also, it needs to be clarified what the purpose of the rearing is. Is it for initial studies of the basic biology of an insect species (Berthier et al., 2010)? Is a rearing initiated for optimization of growth conditions? Is the aim to upscale insect production to a large scale, industrial production?

There are different scales at which insects are reared, that span several orders of magnitude. Each scale requires specific knowledge and circumstances: (1) small laboratory scale; (2) large laboratory or small commercial scale; (3) commercial big scale. The three levels of insect rearing reflect the purpose of rearing. Small laboratory scale rearing has the purpose to produce hundreds of well characterized individuals to be used in scientific experiments. An important issue in small scale rearing is to ensure optimal conditions for each individual insect to complete its life cycle. To this end incubators are often used in which temperature, light intensity and in some cases humidity can be controlled. Insect food (natural or artificial) can be precisely dosed and a detailed daily monitoring of the health status of all individuals and a subsequent removal of diseased or aberrant individuals can be practiced (Eilenberg et al., 2015). In this way it is possible to maintain a high quality, but costly rearing stock (when measured in costs per individual). Turning to large laboratory or small commercial scale rearing the main point is to ensure a stable production of thousands of individuals per week, for example for large, routine testing of effects of chemical substances or microorganisms on insect fitness. Since production mostly takes place in rooms or glasshouses rather than in incubators, rearing conditions are variable over time and space of the facility and the focus is on the production output rather than on the quality of each individual insect, nevertheless monitoring health status is essential. The third type of insect rearing, large scale commercial production, is in many ways completely different compared to laboratory scale rearing. The scale of production is measured in tons of insect biomass produced per week rather than number of insects produced per week. Production can take place in large factory-like facilities, equipped to maintain an optimal temperature and light regime. Larvae (or nymphs) and adults are best kept in different buildings to spread the risk if an inadvertent outbreak of disease would occur. Diet for the insects should be optimised, but has to be balanced with its costs. The normal way to scale up a rearing to mass production is to start with small scale rearing, which is expanded when sufficient experience is achieved. A good advice is to keep small portions of the reared insects in a physically separated facility in order to be able to re-start the rearing with new individuals if needed.

A fundamental challenge at all rearing scales is posed by obligate or facultative insect diseases. Each insect species studied harbors a set of specialized pathogens, including viruses, bacteria, fungi, protists and other types of microorganisms. Insect pathogenic viruses (Nuclear Polyhedrosis Virus (NPV), Granulosis virus (GV) and other types), are specialists only infecting one or a few host species, can be present as latent infections, which often go undetected until a rapid developing epidemic breaks out. Viral diseases are often a challenge in rearing of for example crickets, butterflies and moths. Insect pathogenic fungi include generalist species (*e.g.* species from the genera *Beauveria* and *Metarhizium*), which can infect almost all types of insects. Also among fungi there are specialists, namely entomophthoralean fungi, which can rapidly develop into an epidemic. The insect pathogenic bacteria occurring in rearings are often generalist, facultative insect pathogens (*Serratia* and *Pseudomonas*), which will mainly attack insects that are in a poor physiological state, *e.g.* insects kept at too high humidity.

7 Conclusions

The class Insecta comprises a very large number of species with highly diverse life styles. Insects have three major body parts, head, thorax and abdomen. Insect body structure is shaped by an exoskeleton that has a layered, sclerotised cuticle that protects against water loss and enemies. The exoskeleton grows in discrete phases that are separated by moults by which the cuticle of the previous phase is shed. The digestive system of insects shows a wide diversity in gut morphology and function depending on the diet consumed. The gut has three regions, foregut, midgut, and hindgut of which the midgut is the main site of absorption of nutrients through the gut wall into the haemolymph. Typical for insects is the peritrophic membrane, a tubular structure inside the midgut that has protective functions. In the past decade the interest in symbiotic microbes in the gut has steeply increased in view of their important roles in insect nutrition and health and the increased availability of molecular identification techniques. When collecting or sampling insects in the field as starting material to establish a rearing, knowledge of their biology is essential. A sufficiently large number of individuals to constitute the founder population is important to encompass the species' genetic variation. To sustain the health of captive insect populations, knowledge about insect diseases is important to avoid epidemics in production stock. Increase of our understanding of insect biology and their interactions with microbes is needed in order to realize the full potential of insects as food and feed.

Acknowledgements Stijn Schreven (Laboratory of Entomology, Wageningen University, The Netherlands) permitted us to use his drawing of the gut of the House cricket as Fig. 5.

References

Berthier K, Chapuis MP, Simpson SJ, Ferenz HJ, Habib Kane CM, Kang L, Lange A, Ott SR, Babah Ebbe MA, Rodenburg KW, Rogers SM, Torto B, Vanden BJ, van Loon JJA, Sword GA (2010) Laboratory populations as a resource for understanding the relationship between genotypes and phenotypes: a global case study in locusts. Adv Insect Physiol 39:1–37

Chapman RF, Simpson SJ, Douglas AE (2013) The Insects: Structure and Function. Cambridge University Press, Cambridge, 929 pp

Eilenberg J, Vlak JM, Nielsen-LeRoux C, Cappellozza S, Jensen AB (2015) Diseases in insects produced for food and feed. J Insects Food Feed 1:87–102

Gullan PJ, Cranston PS, McInnes KH (2014) The Insects: An Outline of Entomology. Wiley-Blackwell, Chichester, 595 pp

Van Huis A, Tomberlin JK (eds.) (2017) Insect as Food and Feed – from Production to consumption. Wageningen Academic Publishers, The Netherlands, 447 pp

Part II
Culture

Insect Consumption in the Arctic

Maria Pontes Ferreira, Alain Cuerrier, Marjolaine Giroux, and Christian H. Norton

Abstract The Inuit live in the circumpolar regions of Greenland, Canada, USA, and eastern Russia. Largely a maritime culture, the Inuit also rely upon caribou (*Rangifer tarandus* L.) for sustenance. The Oestridae flies *Hypoderma (Oedemagena) tarandi* (L.) and *Cephenemyia trompe* (M.) commonly infect caribou with their larvae. The Oestridae larvae grow under the hides or in the nasopharyngeal cavities of caribou. When Inuit harvest the caribou, the grubs may be collected and eaten, too. While a fading practice, there is a rich history and lore about the Inuit and edible insects. This history is brought to life in this chapter on traditions for eating insects in North American Arctic cultures. Herein, we provide a biological overview of the Oestrid flies, including a discussion of the strengths and weaknesses of what is known about the nutritional benefits of Oestridae larvae to Inuit food security and food innovation. The chapter concludes with a discussion about how insect farming in the north by Indigenous peoples may provide a modern way to address bio-waste problems in a productive way.

1 Introduction

The Inuit people inhabit vast circumpolar regions of the world, and they are known for their resilience and adaptation in the harsh environment of the Arctic and Subarctic. They survive on account of their ability to adapt to environmental challenges, as well as their intimate knowledge of the land and sea. Most papers

M. P. Ferreira (✉)
Feeding Windsor, Windsor, ON, Canada
e-mail: maria.pontes.ferreira@fulbrightmail.org

A. Cuerrier · C. H. Norton
Jardin Botanique de Montréal. Institut de Recherche en Biologie Végétale,
Université de Montréal, Montréal, QC, Canada
e-mail: alain_cuerrier@ville.montreal.qc.ca; christian.norton@umontreal.ca

M. Giroux
Insectarium de Montréal. Espace pour la vie, Montréal, QC, Canada
e-mail: marjolaine.giroux@ville.montreal.qc.ca

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_2

have emphasised the animal component of their diet (Kuhnlein and Receveur 2007). Recently, Cuerrier and Elders of Kangiqsujuaq (2011) showed that Inuit also rely on plants for food and medicines. Interviews based on Inuit plant and animal knowledge (Cuerrier and Elders of Kangiqsujuaq 2011) have shown that the Inuit would also eat insects (*quppiruaruit*) as food while hunting or walking in the tundra (Cuerrier and Elders of Kangiqsualujjuaq 2012). We wish to further understand Inuit consumption of insects using literature and our own data to elaborate on insect eating behaviour amongst the Inuit of Greenland, Canada (Inuvialuit, Nunatsiavut, Nunavik, and Nunavut), Alaska, and Russia. Is insect eating a random activity? Or is it actively pursued? Are there differences between the various groups? Based on our current data, could we say that entomophagy in the circumpolar region is a component of Arctic food security? In this chapter, we will consider how entomophagy has historically fit into Inuit culture and food security, and contemplate how Inuit adaptability in the twenty-first century may include novel approaches to Inuit entomophagy and food innovation.

2 Inuit Migration

Inuit worldwide share a common cultural heritage, which may explain the similarity amongst stories about eating insects. Inuit have lived in the North American Arctic for at least the last 800 years (Friesen and Arnold 2008). The Inuit were the last indigenous group to migrate into what is now present-day North America. There were two migrations of Indigenous peoples across the Bering Sea into what is present-day Alaska (Helgason et al. 2006). The first group, the Paleo-Eskimos, crossed approximately 4000–4500 years ago. The second group, the Neo-Eskimos, crossed approximately 800–1000 years ago. Inuit are descendants of the Thule, who are in turn descendants of the Neo-Eskimos. The Thule people were an indigenous culture that developed from the Neo-Eskimos, and whose economy was heavily based on the utilisation of marine resources, namely seal and whale. In addition to the Inuit in Canada, the Neo-Eskimos are also directly related to present-day indigenous cultures in Alaska and Greenland.

3 Inuit and Insects

Although the Inuit do consume insects, they represent a taxon with which the Inuit have never felt at ease. Butterflies (*saralikitait* in Inuktitut) and bumblebees (*igutsait* in Inuktitut) bring fear to Inuit. The Inuit also have great respect for all creatures, and that respect extends to insects. Cuerrier and Elders of Kangiqsualujjuaq (2012) recount a story told by an Inuk of Kangiqsualujjuaq about a mosquito (*kitturiaq*) that was captured and released during wintertime by the Inuk who wanted to teach the mosquito a lesson. It turns out that the Inuk is the one who dies and the mosquito survives:

> *Everyone loses patience with mosquitoes, and it is easy to lose your mind if there are a lot of them. This is what happened to an Inuk who decided to catch one in a jar so that he could let it go in January, the coldest month. He set to work trying to keep the mosquito alive; it had become his companion. January came, and the Inuk went outside to put his plan into action. He went far away from his house to let the mosquito go. He then began to run home for shelter before the mosquito could catch up to him. While running to his house, he stopped, frozen in place. The mosquito overtook him and returned inside the house. The Inuk died. This story reminds us of the concept of respect. If we do not show respect, something will happen to remind us of it* (*Cuerrier and Elders of Kangiqsualujjuaq* 2012).

This story exemplifies the respect that Inuit have for all beings, even if they do express aversion to insects. Inuit see all beings as part of, or coming from the land (Cuerrier and Elders of Kangiqsualujjuaq 2012). Like First Nations and Métis people, Inuit vow respect to their land (see Freeman 1976; Cuerrier et al. 2012):

> *We like our land, we like our natural foods. They give us the freedom to do what we want, the kind of life we like to live. Our culture we'll never forget. To keep our culture, we got to keep our land and have it free from being developed, so we'd kind of like to protect the land where we trap and hunt all our lives. Sam Raddi, Inuvik, Inuvialuit Settlement Region* (*Freeman* 1976).

4 Inuit Land

Inuit most often inhabit coastal lands, and they have a rich maritime heritage. Marine organisms remain of utmost importance to their culture. Biodiversity in the Arctic is surprisingly varied (Jensen and Christensen 2003), but the Arctic biomass is largely found in the ocean. Nonetheless, as much as the tundra may appear barren, it still supports a community of plants, birds, mammals, and insects, especially when the flora flourishes in the brief Arctic summer. The tundra also supports caribou (*Tutu* in Greenlandic), and caribou are as essential to Inuit culture and diet as any marine organism.

The Arctic Council estimates that there are over 4 million people inhabiting the circumpolar Arctic (Tesar and Eskeland 2010). The majority of the Arctic population is non-indigenous (except for Greenland and Canada), but there are over 30 indigenous groups and many language families (Fig. 1), not including the state languages. Indigenous groupings generally include the Sami (or Laplanders) of the Nordic countries and Russia, the Yupik (Eskimo-Aleut language family) of Eastern Russia and Alaska, and the Inuit (Eskimo-Aleut language family) of northern Alaska, Canada, and Greenland. The Inuit are by far the world's most widely dispersed people speaking a common language. Therefore, the number of Indigenous and non-indigenous languages in the circumpolar Arctic region serves as an obstacle for researchers, and therefore the chapter authors to produce a comprehensive survey of Arctic entomophagy, due to language barriers.

Fig. 1 A circumpolar view of Arctic and Subarctic inhabitants and languages (Ahlenius 2010)

5 Inuit Food-Ways

While a maritime culture, there is considerable variation in means of obtaining sustenance in such a widely dispersed people as the Inuit, and other Arctic Indigenous peoples. The Soviet ethnographers Levin and Cheboksarov (1955) outlined the subsistence methods of Indigenous peoples in the Eurasian Arctic Zone, which is frequently adapted to other Arctic regions: Arctic marine hunters, caribou herders of the tundra, hunters of tundra and forest tundra, hunters and reindeer herders of taiga (boreal forest), taiga hunters and fishermen, and fishermen of the large river basins. Hunting of marine-based mammals (e.g., whale, seal, and walrus) and sea fishing (e.g., Arctic char and salmon) are central to many.

Food gathering and harvesting depend upon local and seasonal supplies, and is impacted by regional and seasonal migrations of mammals, fishes, and birds. Insects are also consumed in the traditional Inuit diet.

6 Observations of Traditional Consumption of Insects in the Arctic

In the Arctic and Subarctic habitats, peoples from various cultural groups engaged in traditional consumption of insects. Traditionally, the Inuit collected two species of Oestridae larvae present in the hides (Fig. 2) or in the nasopharyngeal cavities (Fig. 4) of caribou. Ostridae larvae are sometimes called warble grubs or caribou grubs. There is ample evidence that Oestrid larvae were consumed by Arctic and Subarctic peoples, based on sampling of field notes from the beginning of the twentieth century until recent times. The vast majority of these field notes are from persons of European/Caucasian heritage; a notable exception is Rasmussen who was part Greenlandic Inuit:

Fig. 2 Inuk carefully removes Oestrid warbles from caribou hide with ulu (female knife) (Archives/©GNWT Department of Information/ G-1979-023:1417)

They are always eaten raw and alive out of the skin and are said by those who like them to be as fine as gooseberries. (*Russell* 1898)

In the spring the backs of the deer are covered with parasites that spoil the skin by eating holes in them. They are an inch long, one-fourth of an inch in diameter, tapering at both ends, and cream colored. The natives say that they eventually turn to butterflies. These parasites are eaten raw and considered a delicacy. My disgust when offered them was regarded as ridiculous. (*Stoney* 1900)

Chukchee herdsmen very dexterously pick out these maggots, when large enough, from the reindeer's back, and eat them with great relish. The Lamut sometimes gather a quantity and boil them in water. (Bogoras 1904 -1909)

There is an interesting reference in the October 1918 Ottawa Naturalist by R. M. Anderson to the edibility of caribou warble grubs. He states that the Eskimos pick out the grubs from the hides in the spring and eat them like cherries and adds, apparently from experience, that they are very watery and absolutely tasteless. (Felt 1918)

The grubs of the warble fly, which bore through the skins of the caribou in the spring, are picked out and eaten, either raw or boiled. (Jenness 1922)

Then came dessert; but this was literally more than we could swallow. It consisted of the larvae of the caribou fly, great fat maggoty things served up raw just as they had been picked out from the skin of the beasts when shot. They lay squirming on a platter like a tin of huge gentles, and gave a nasty little crunch under the teeth, like crushing a black-beetle. Igjugarjuk, ever watchful, noted my embarrassment and observed kindly: No one will be offended if you do not understand our food; we all have our different customs. But he added a trifle maliciously: After all, you have just been eating caribou meat; and what are these but a sort of little eggs nourished on the juices of that meat? (Rasmussen 1927)

… larvae from the caribou hide (tugtup kumait) are often eaten, though more to quench thirst than to appease hunger, as they taste like water. Hall says that the Aiviliks were very fond of soup made of these. (Mathiassen 1928)

In May, whenever caribou are skinned, the larvae of the caribou warble fly, which have reached their greatest size prior to pupation, are eaten by the Nunamiut. These larvae are often found in large numbers lying just below the skin on the back, and are eaten alive as they are removed from the small pocket of inflammatory tissue surrounding them. (Rausch 1951)

The larvae are edible, and when they are boiled with the meat they resemble a soft, spongy nut. Nunamiut sometimes tease their children by saying that if they eat boiled nostril fly larvae, the grizzly bear will never catch them. This is done in jest, and no real meaning is attached. (Gubser 1965)

… the caribou are hosts to a parasitic fly called the warble whose larva penetrate the hide in great numbers. Often, the inside of the throat of a caribou is a mass of wiggling, nasty grubs. The Chipewyans sometimes gouge them out and eat them. (Downes 2004)

It seems though, that the practice of eating these insects has progressively declined, and the transition from nomadic to sedentary Inuit lifestyles may be a factor:

Notes were obtained on seven of the men and boys who visited the Windy River at various times in 1947, and two of the children who had recently been rescued from starvation and adopted by Charles Schweder, who maintained the trading post…. The two Eskimo children were Anoteelik, a boy of approximately fifteen, and Kukwik, a girl of approximately five....

> *Rita (as the erstwhile Kukwik was now called "for short")… Through 1947 Anoteelik apparently retained most of the eating habits of his people, while Rita being so much younger, readily adopted more civilized ways. In the early part of the summer these two carried on their housekeeping separately from the rest of the camp on Windy River. They occupied a little log hut, where a homemade stove (originally an oil drum) was available for cooking. Since they ate their fish raw, and their caribou half raw, segregation from the rest of the camp at mealtimes was understandable. They used the stove for making bannock, tea, and a sort of thick gravy composed of flour and lard. Anoteelik still ate, and liked, raw caribou warbles (the larvae of the parasitic warble fly,* Oedemagena tarandi*), while Rita soon abandoned the habit.* (Harper 1964)

> *Twenty-five years ago I was doing a necropsy on a caribou in the western Canadian Arctic and picked up a warble maggot and popped it into my mouth, primarily to see the reaction of a group of Inuit teenage students who were observing. They couldn't believe their eyes and expressed some revulsion that turned to derision when I said I thought I was just doing something their ancestors were supposed to have done. They just shook their heads. So I'd check the authenticity of those old stories. Maybe it has since fallen out of fashion.* (Murray Lankester 2017; pers. comm.)

Milugiaqjuaq, the Inuktitut name of the caribou parasite, was still eaten in 2004 in the Canadian Arctic by some Elders. For example, the late Willie Emudluk was fond of the honey-tasting larvae:

> *Milugiarjuaq; this name refers to flies whose larvae live in, and pierce, the skin of the caribou. Inside the larvae is a honey-like liquid that is very much appreciated by the Inuit.* (Cuerrier and Elders of Kangiqsualujjuaq 2012).

6.1 What Is an Oestridae Fly?

Adult Oestrids are robust, often beelike, flies (Fig. 3). They are distinct from other flies by having non-functional mouthparts and by being obligate parasites as larvae in the tissues of mammals. As adults, they rely on stored fat accumulated as larvae. The fly cannot complete its lifecycle without a host species (Wood 1987; Anderson 2006).

Arctic Indigenous peoples traditionally ate the larvae of two species: the caribou warble fly (*Hypoderma tarandi*) and the caribou nose bot fly (*Cephenemyia trompe*). They commonly infect caribou (*Rangifer tarandus*) throughout most of its circumpolar distribution. Although caribou are primary hosts for *H. tarandi*, larval infestations have been reported from other species, such as muskoxen *Ovibos moschatus* (Z.) and red deer *Cervus elaphus* (L.) (Samuelsson et al. 2013). *C. trompe* also attack deer (*Cervus spp., Odocoileus* spp.) and moose (*Alces alces* L.).

In the short Arctic summer, females of *H. tarandi* lay their eggs in the fur of the ungulates while those of *C. trompe* eject first instar larvae onto the host (Colwell et al. 2006). After hatching, young larvae undergo a migration through the body tissues. They burrow down under the hide, typically on either side of the host's spine (*H. tarandi*), or in nasal cavities and the pharynx (*C. trompe*) (Fig. 4). Well-fixed in their host, the larvae become fatter over the winter. *H. tarandi* larvae remain enclosed in a subcutaneous pouch that produces the familiar swellings known as warbles.

Fig. 3 *Oestrid* fly in Puvirnituq, Québec, Canada (Insectarium de Montréal, Maxim Larrivée)

Fig. 4 Larvae of *C. trompe* in retropharyngeal (throat) pouches of a caribou, in central Newfoundland, Canada (Murray Lankester)

At the beginning of the summer, larvae leave their host, bury themselves in the ground, and pupate. About two weeks later, adult flies emerge, mate, and lay eggs, thus continuing the lifecycle. Oestrid larvae numbers in caribou vary widely between populations and individuals. In North America, mean warble numbers in caribou cows of 38 are usually observed, although over 100 larvae are common. These means range from roughly double to eight times greater in caribou populations of west Greenland. Oestrid larvae occur in 97–100% of caribou, and calves or juveniles generally have greater larval infections than adults, and bulls more so than cows (Cuyler et al. 2012). Caribou herds are incessantly pestered by the flies, and are frequently on the move in an often unsuccessful attempt to evade them (Folstad et al. 1991; Anderson and Nilssen 1996; Cuyler et al. 2012).

6.2 Nutritional Composition of Oestridae Larvae

There is little in the literature about the precise nutritional composition of Oestridae larvae. This lack of references regarding the nutrient composition suggests a need for future research. However, according to some observations made in the field, these larvae may likely be similar to other Diptera species in nutrient composition, being a source of fat and protein (Rumpold and Schlüter 2013) and thus, nutrient dense.

In 1996 Anderson and Nilssen evaluated the amount of fat body in the haemocoele (abdominal cavity) of trapped female Oestrids (laboratory-reared, non-inseminated, and females caught in copula, in wild). They found that young females (1–3 day old) are rich in fat. It would not be surprising then that Oestrid larvae have a fatty taste and may be somewhat comparable to Palm Weevil larvae, a Coleoptera larva eaten by some tropical Indigenous groups. Weevil larvae are sources of unsaturated fats, proteins, minerals and vitamins (see for example Santos Oliveira et al. 1976). Thus, it seems likely that Arctic insects traditionally consumed as country food, or traditional food, are nutritious, yet precise nutrient composition by weight (wet and dry, per 100 g) is absent from the literature (Rumbold and Schluters 2013). This information is important, and once obtained, will be a significant asset to nutrient databases (Kuhnlein and Humphries 2017).

6.3 Other Insects and Insect Products Eaten in the Arctic

6.3.1 Blowfly Maggots

Warble fly larvae are an original country food consumed by the Inuit. However, records indicate that this was not the only insect consumed. Knud Rasmussen—along his expansive travels amongst the Inuit—listened intently to the Elders and also learned from direct experience while living and hunting amongst the different groups. Rasmussen (1931) made this observation, which suggests that the maggots of blowflies (Calliphoridae: Diptera) were also eaten by Inuit in the Canadian central Arctic:

> *Right alongside the spot where we pitched our camp we found an old cache of caribou meat two years old I was told. We cleared the stones away and fed the dogs, for it is law in this country that as soon as a cache is more than a winter and a summer old, it falls to the one who has use for it. The meat was green with age, and when we made a cut in it, it was like the bursting of a boil, so full of great white maggots was it. To my horror my companions scooped out handfuls of the crawling things and ate them with evident relish. I criticised their taste, but they laughed at me and said, not illogically: You yourself like caribou meat, and what are these maggots but live caribou meat? They taste just the same as the meat and are refreshing to the mouth.* (Rasmussen 1931)

6.3.2 Bumblebees and Their Honey

> *Apis mellifica, the real honey bee, does not exist in Greenland, whereas two species of the genus Bombus occur. Their resorts are sometimes dug out for the sake of the honey.* (Birket-Smith 1924)

Bumblebees do not actually make true honey. Bumblebees gather nectar and store it, for a short time, in small pots made of wax. They do not produce honey because their small colony size does not require it and also because they store nectar only to meet the colony's short-term needs. Contrary to the honeybee, only young fertilized queens survive the winter. Most bumblebee colonies are made up of around 150 to 300 workers, whereas a honeybee colony may sometimes have more than 60,000 individuals.

DeFoliart (1991) published a list of species that were used as foods by North American Indigenous peoples, and four species of bumblebees were listed have been eaten as larva and pupa, including honey. In Labrador, a story remembered by a number of Inuit from Postville, Nunatsiavut detailed how one Inuk kept squeezing the 'honey' out of the bumblebee (*igutsaq* in Inuktitut) body (Cuerrier et al. unpubl. data). Although the story has not been confirmed yet, Inuit know that certain flowers have nectar and they do eat them as delicacies, especially as they walk in the tundra. In this story, it is possible that the Oestridae fly was mistakenly called bumblebee, although the Inuktitut names are phonetically quite different, *igutsaq* versus *milugiaqjuaq*.

6.3.3 Sawflies Larvae

Sawflies (*Pontania* spp.; Hymenoptera) are known to lay their eggs in willow leaf tissue; a reddish gall then forms within which the larvae reach maturity and adulthood (Fig. 5). Inuit of Nunavik (Cuerrier and Elders of Kangiqsujuaq 2011) were eating the whole gall including the larvae. Some Inuit have voiced concerns over the notion that these larvae could become human parasites (Cuerrier pers. obs.). Although galls are formed on most willows, Inuit tend to prefer the ones found on

Fig. 5 Gall on a leaf of *Salix herbacea* L. (snowbed willow); a Sawfly's larvae (*Pontania* spp.; Hymenoptera) lays inside it, in Kangiqsujuaq (Nunavik, QC), Canada (Alain Cuerrier)

the snowbed willow, *Salix herbacea* L. This eating habit seems to have waned, as members of other Inuit communities have never mentioned this habit when galls were shown to them.

7 Transition from Traditional Inuit Diet to Westernized Dietary Patterns

Western influence may be responsible for the reduction of entomophagy in Inuit culture. One cannot exclude the impact of the caribou decline seen over the recent years, due to anthropogenic land and climate changes (Vors and Boyce 2009), and hunting pressures. Westerners generally are not entomophagous and react to the notion of eating insects with disgust (Schrader et al. 2016). It is therefore not surprising that Western-educated nutrition scientists and dieticians have done an incomplete job of assessing the value of insects to the diet of Inuit. Current research instruments, such as the quantitative food frequency questionnaire, claimed to be a 'culturally appropriate...complete list of foods' might need to be expanded for pan-Inuit use (Sheehy et al. 2013). It will be important for future researchers to develop nutrition assessment tools (e.g., food frequency questionnaires, 24 h recall interview methodology, food record instructions, and food composition databases/tables) to include insect-based foods, in conjunction with positive messaging about insect consumption. Culturally sensitive research will facilitate the gathering of accurate data regarding documentation of Indigenous peoples' foods and foods systems and thus allow for nutrient composition analysis (Kuhnlein 2014). This information can be used to support the benefits of indigenous foods.

8 Considerations for Insect Farming in the Arctic

The transition from nomadic to sedentary lifestyles is one of the most significant impacts on the Inuit, and this transition has caused social problems for the Inuit and environmental problems in the Arctic. One major problem is the accumulation of wastes due to a lack of waste-management solutions adapted to the Arctic. This problem is widespread throughout the circumpolar region (Sanschagrin 2016). Bournérias (1971) concluded, about pollution from household wastes in an Arctic village of Nouveau-Québec, that:

> *"...le retour au cycle biologique des divers déchets est la solution la mieux adaptée au milieu arctique..."* (…return of the various wastes to the biological cycle is the best solution in the Arctic environment).

Today, biotechnology is being used to solve the environmental and social impacts associated with a sedentary lifestyle in the Arctic. For example, there are composting facilities in several northern communities in the Northwest Territories (Dessureault et al. 2014). The resulting compost can also be used in community greenhouse projects that help reduce the dependence of northern communities on market gardening supplies (Dessureault et al. 2014; Sanschagrin 2016). Insect farming in the Arctic could be a sustainable way to not only make good use of organic wastes, but to also produce low-input feed. A new animal feed, namely the Black soldier fly larvae (*Hermetia illucens* L.), is based on organic ingredients and is being studied in an Icelandic land-based aquaculture farm (Smárason et al. 2017). It is quite possible that similar projects could be considered for other Nordic countries (Lindberg et al. 2016), Canada (Enterra 2016), and Greenland.

Using new technologies, Northern communities could also use their organic waste to farm insects for consumption. According to Dessureault et al. (2014), organic waste constituted 21% of the total residual materials from a northern and isolated community of Nunavik (Québec). In Nunavik, plant waste is rare or non-existent, but animal carcasses and food scraps are common. Therefore, the combination of waste utilisation capacity together with the generation of a valuable product makes insects technology a potential tool for waste management (Lalander et al. 2014) in low and middle-income countries (Diener et al. 2011).

9 Parting Thoughts

It is difficult to provide a comprehensive survey of past and present practices of insect eating in the circumpolar Arctic, due to language barriers. Despite this shortcoming, the authors report that while insects were once eaten frequently, there is a reduction in the consumption of insects in Arctic and Subarctic regions. Acculturation and the decline of caribou in the last 10–15 years have had a toll on this habit. With insects being at the core of multiple stories and folktales (Inukpuk and POV 2006; Laugrand and Oosten 2010), however, it might not be long until a new chapter unfolds on the role of insect foods (Bodenheimer 1951) in northern communities. Boas (1901:226–227) recounted a south Baffin Island story dealing with a woman and her daughter who were left behind without food:

> *The people had left nothing for the women to eat, who gathered insects [ea-kan] for food. One day while they were out looking for insects, the old woman was attacked by an ermine, which bit her on several parts of her body. Her skin fell off, disclosing a fresh, new skin underneath, such as a much younger person might have. The insects had taken compassion on the poor old woman, and had asked the ermine to bite off the old skin, that she might be rejuvenated. The daughter was grateful to the insects for doing so much for her mother. After a time the people sent for the two women to come to their new camping-place, but, as they had never sent them any food since they had been away, the women did not go. They went instead to live with the insects, and both took husbands from among them…The next year the women went to the camping place where the people had gone. They told them how kind the insects had been to them,— how they had given them food, and had asked them to come and live with them; how the old woman had remarked to them that she should look much better if she could only be made younger-looking, and how they had told an ermine to bite all her old skin, and cause it to fall off* (*Boas* 1901).

Perhaps—and partly due to such folktales and how they address the cultural ties Inuit have with insects— one can speculate how an older tradition of eating insects may be revived amongst the Inuit, with positive benefits.

Acknowledgements The authors express gratitude toward Dr. John D. Speth (University of Michigan) and Katrina McClure, PhDc (University of Kansas). Each provided feedback on the manuscript. The authors acknowledge the Inuit from Nunavik (Kangiqsujuaq and Kangiqsualujjuaq) and Nunatsiavut (Postville) for sharing their knowledge. Avataq Cultural Institute and ArcticNet financially sponsored the research project in those Inuit lands. We also wish to extend our thanks to Dr. Murray Lankester (Oklahoma State University) for sharing his experience in entomophagy and for the rights to use his pictures, and as well to Dr. Maxim Larrivée (Insectarium de Montréal) for the institution's support and financial contribution.

References

Ahlenius H (2010) "Demography of Indigenous Peoples of the Arctic Based on Linguistic Groups". GRID-Arendal, Arctic Biodiversity Trends 2010. www.grida.no/resources/6254

Anderson JR (2006) Adult biology. In: Colwell DD et al (eds) The Oestrid flies. Biology, host-parasite relationships, impact and management. CABI Publishing, Wallingford, pp 140–166

Anderson JR, Nilssen AC (1996) Trapping oestrid parasites of reindeer: the relative age, fat body content and gonotrophic conditions of *Cephenemyia trompe* and *Hypoderma tarandi* females caught in baited traps. Med Vet Entomol 10(4):347–353

Birket-Smith K (1924) Ethnography of the Egedesminde district with aspects of the general culture of west Greenland. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=22&disp=42900&disp=honey. Accessed 17 Feb 2017

Boas F (1901) The Eskimo of Baffin Island and Hudson Bay. From notes collected by Capt. George Comer, Capt. James S. Mutch and Rev. E.J. Peck. Bull Am Mus Nat Hist 15(1):1–370

Bodenheimer FS (1951) Insects as human food, a chapter to the ecology of man. W J. Publishers, The Hague

Bogoras W (1904–1909) The Chukchee. In: The jesup North Pacific expedition. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017

Bournérias M (1971) Le problème de la pollution par les déchets domestiques dans un village arctique : Puvirnituq, Nouveau-Québec. Cahier de géographie du Québec, Québec 15(36):559–568

Colwell DD, Hall MJR, Scholl PJ (2006) A synopsis of the biology, hosts, distribution, disease significance and management of the genera. In: Colwell DD et al (eds) The Oestrid flies. Biology, host-parasite relationships, impact and management. Commonwealth Agricultural Bureau International, CABI Publishing, Wallingford. p 140–166

Cuerrier A, Elders of Kangiqsujuaq (2011) The botanical knowledge of the Inuit of Kangiqsujuaq, Nunavik. Avataq Cultural Institute, Montreal

Cuerrier A, Elders of Kangiqsualujjuaq (2012) The zoological knowledge of the Inuit of Kangiqssualujjuaq, Nunavik. Avataq Cultural Institute, Montreal

Cuerrier A, Downing A, Johnstone J et al (2012) Our plants, our land: bridging aboriginal generations through cross-cultural plant workshops. Polar Geogr 35(3–4):195–210

Cuyler C, White RR, Lewis K et al (2012) Are warbles and bots related to reproductive status in west Greenland caribou? Rangifer Special, 20:243–257

DeFoliart G (1991) Toward a recipe file and manuals on "how to collect" edible wild insects in North America. The food insects. Newsletter 4(3):11

Dessureault PL, Grégoire V, Côté H (2014) Gestion des matières résiduelles en territoire nordique :Portrait de la situation. Chaire en éco-conseil, Université du Québec à Chicoutimi. p 144
Diener S, Zurbrügg C, Gutiérrez FR, et al (2011) Black soldier fly larvae for organic waste treatment prospects and constraints. In: Conference: WasteSafe 2011, 2nd international conference on solid waste management in developing countries, Khulna, Bangladesh, 13–15 February 2011
Downes PG (2004 [1943]) Sleeping Island: a journey to the edge of the barrens. Ferrisburg, Heron Dance Press
Enterra (2016) Enterra Feed Corporation. http://www.enterrafeed.com/. Accessed 11 Mar 2017
Felt EP (1918) Caribou warble grubs edible. J Econ Entomol 11:482
Folstad I, Nilssen AC, Halvorsen O et al (1991) Parasite avoidance: the cause of post-calving migrations in *Rangifer*? Can J Zool 69:2423–2429
Freeman MMR (ed) (1976) Land use and occupancy; Inuit land use and occupancy project report. Supply and Services Canada, Ottawa
Friesen TM, Arnold CD (2008) The timing of the Thule migration: new dates from the western Canadian Arctic. Am Antiq 73(3):527–538
Gubser NJ (1965) The Nunamiut Eskimos: hunters of caribou. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017
Harper F (1964) Caribou Eskimos of the upper Kazan River, Keewatin. The Allen Press Lawrence, Kansas, p 90
Helgason A, Pálsson G, Pedersen HS et al (2006) mtDNA variation in Inuit populations of Greenland and Canada: migration history and population structure. Am J Phys Anthropol 130:123–134
Inukpuk E, POV S (2006) Unikkaangualaurtaa: let's tell a story. Avataq Cultural Institute, Montreal
Jenness D (1922) The life of the copper Eskimos. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017
Jensen DB, Christensen KS (2003) The biodiversity of Greenland – a country study. Technical report no. 55, Pinngortitaleriffik, Grønlands Naturinstitut, Nuuk
Kuhnlein HV (2014) Food system sustainability for health and well-being of Indigenous Peoples. Public Health Nutr 1(13):1–10
Kuhnlein HV, Humphries MM (2017) Traditional animal foods of Indigenous peoples of northern North America: http://traditionalanimalfoods.org/ Centre for Indigenous Peoples' Nutrition and Environment. McGill University, Montreal
Kuhnlein HV, Receveur O (2007) Local cultural animal food contributes high levels of nutrients for arctic Canadian Indigenous adults and children. J Nutr 137:1110–1114
Lalander CH, Fidjeland J, Diener S, Eriksson S, Vinneras B (2014) High waste-to-biomass conversion and efficient *Salmonella* spp. reduction using black soldier fly for waste recycling. Agron Sustain Dev 35(1):261–271
Laugrand F, Oosten J (2010) Qupirruit: insects and worms in Inuit traditions. Arctic Anthropol 47(1):1–21
Levin MG, Cheboksarov NN (1955) Economic-cultural types and historical-ethnographic areas. Sov Etnogr 4:3–17
Lindberg JE, Lindberg G, Teräset J et al (2016) In: Andersen K, Tybirk K (eds) Nordic alternative protein potentials, mapping of regional bioeconomy opportunities. Nordic Council of Ministers, Copenhagen, p 131
Mathiassen T (1928) Material culture of the Iglulik eskimos. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017
Rasmussen K (1927) Across Arctic America: narrative of the fifth thule expedition available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017

Rasmussen K (1931) The Netsilik Eskimos: social life and spiritual culture. Available via Hubert Wenger Eskimo Database. http://www.wengereskimodb.uaf.edu/wenger.aspx?page=more&disp=43&disp=7600&disp=maggot. Accessed 17 Feb 2017

Rausch R (1951) Notes on the Nunamiut Eskimo and mammals of the Anaktuvuk Pass region, Brooks Range, Alaska. Arctic 4(3):147–195

Rumpold BA, Schlüter OK (2013) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57(5):802–823. Doi:10.1002/mnfr.201200735

Russell F (1898) Explorations in the far north. Univ Iowa Press, Iowa City, p 228

Samuelsson F, Nejsumb P, Raundrupc K et al (2013) Parasites and wildlife. Int J Parasitol 2:214–216

Sanschagrin A (2016) La question des déchets dans les communautés Inuits du Nord-du-Québec : analyse et réflexions. Mémoire de maîtrise en design de l'environnement, Université du Québec à Montréal. p 189

Santos Oliveira JF, Passos de Carvalho J, Bruno de Sousa RFX, Madalena Simao M (1976) The nutritional value of four species of insects consumed in Angola. Ecol Food Nutr 5:91–97

Schrader J, Oonincx D, Ferreira MP (2016) North American entomophagy. JIFF 2(2):111–120

Sheehy T, Roache C, Sharma S (2013) Eating habits of a population undergoing rapid dietary-transition: portion sizes of traditional and non-traditional foods and beverages consumed by Inuit adults in Nunavut, Canada. Nutr J 12:70

Smárason BÖ, Ögmundarson Ó, Árnason J et al (2017) Life cycle assessment on Icelandic Arctic char fed with three different feed types. Turk J Fish Aquat Sci 17:79–90. https://doi.org/10.4194/1303-2712-v17_1_10

Stoney GM (1900) Naval explorations in Alaska: an account of two naval expeditions to northern Alaska, with official maps of the country explored, 2nd edn. United States Naval Institute, Annapolis, pp 37–51, 56–57, 61–62, 78–100; sketch, p 103; illus.; map 1 from 1900 ed. and map 2 from 1974

Tesar C, Eskeland L (eds) (2010) The circle. WWF International Arctic Programme, Oslo

Vors LS, Boyce MS (2009) Global declines of caribou and reindeer. Glob Chang Biol 15:2626–2633. https://doi.org/10.1111/j.1365-2486.2009.01974.x

Wood M (1987) Oestridae. In: McAlpine JF et al (eds) Manual of nearctic diptera. Canadian Government Publishing Centre, Ottawa, pp 1147–1158

An Ethnographic Account of the Role of Edible Insects in the Adi Tribe of Arunachal Pradesh, North-East India

Karsing Megu, Jharna Chakravorty, and Victor Benno Meyer-Rochow

Abstract Tribal Adi of North-East India are a conglomeration of numerous subtribes residing in Arunachal Pradesh, a region considered a biodiversity hotspot. The diversity of insects of the region is reflected by the numerous roles that insects play in the culture of the Adi. Insects are referred to in idioms, songs and stories; Adi creation myths invoke insects, some species are feared, others serve as objects of entertainment or are therapeutically used and a large number of species are appreciated as food. These edible insects are collected from the wild, eaten whole and raw or are being subjected to a variety of preparations for human ingestion. Roasting them and eating them with some ingredients like spices and vegetables are most commonly practiced. Although some species are only seasonally available, others occur the entire year. They are appreciated because they can easily be collected, are cheap and taste good. Nutritional aspects, for instance whether they contain a lot of protein, minerals or vitamins are apparently not considered in decisions on which species to eat and which to avoid. Over-harvesting, as with wild vertebrates, can affect sought after insect species as well and requires attention if Adi customs and traditions involving insects are to survive in the future.

1 Introduction

Arunachal Pradesh, a global biodiversity hotspot (Myer et al. 2000) and a globally important eco-region amongst 200 such identified regions (Olson and Dinerstein 1998), is the largest state of the Indian Union's North Eastern territory and the easternmost state of India as a whole. Arunachal Pradesh lies between 26° 28′ and 29° 30' N latitude and 90° 30′ and 97°30′ E longitude and covers an area of 83,743 sq. km

K. Megu · J. Chakravorty
Biochemical Nutrition Laboratory, Department of Zoology, Rajiv Gandhi University, Itanagar, Arunachal Pradesh, India

V. B. Meyer-Rochow (✉)
Research Institute of Luminous Organisms, Tokyo, Japan

Department of Genetics and Physiology, Oulu University, Oulu, Finland

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_3

that stretches eastward from Bhutan in the west to the boundary with Myanmar in the east. To the north and north-east, the state marks the last frontier of the Indian Union with a 1080 km long border with China (which, however, is disputed by the latter). The state of Arunachal Pradesh is sparsely populated and with 17/km^2 has the lowest population density in India. The state enjoys an average annual precipitation of 2782 mm and an annual temperature mean of 23 °C. The Adi tribe (formerly called Abor by the British) is a conglomeration of many subtribes such as Pa:dam, Minyong, Pa:si, Bori, Bokar-Pailibo-Ramo, Karko, Komkar, Simong, Panggi and Milang.

All Adis, irrespective of subtribe affiliation, have a deep knowledge of the roles of plants and animals in connection with traditional medicines, beliefs, rituals, stories, myths and customs, typical and characteristic of each tribal community handed down orally from generation to generation. Adis are sub Himalayan highland people and the second largest tribe (among the 26 major tribes of Arunachal Pradesh) with a population of 150,000 according to the 2011 census report of the Ministry of Human Resources Development, Government of India. The Adi inhabit the central belt of Arunachal Pradesh along the rivulets and tributaries of the river Siang called Tsangpo River in China and Dibang River locally. Adi menfolk in particular are hunters and trappers, but for their livelihood Adis also practice wet rice cultivation in the foothills and rotational shifting cultivation in hilly areas. Populations in scattered jungle villages are organised in clan clusters.

The Adi traditionally worship many spirits of nature, but the *Donyi-Polo (*Donyi-sun, polo-moon) cult that recognises the sun and moon as the cosmic symbolic power through which the supreme spiritual being, the world-spirit, is made manifest, also has many followers (Chaudhuri 2013). The tenets of traditional practice of the Adis are deep-rooted in the Adis' environment and tribal ethics, supporting a close and, until recently, harmonious relationship with Nature. Adis claim to have existed for at least 800 years, but without a written record an exact historical chronology is unavailable. Adis speak a Tibeto-Burmese language (Van Driem 2001), which was first recognised in 1825–26 by the two British Bedford and Wilcox (Mackenzie 1884: mentioned in Subba and Ghosh 2003). Tribal knowledge passes from generation to generation orally and given the lack of written documents and a multitude of dialects, there is a stark possibility that indigenous wisdom will disappear unless it is recorded while knowledgeable informants are still present in the community. This paper deals specifically with the traditional utilization of insects in the daily life of the Adi; it catalogues the indigenous knowledge system and in this way helps to prevent that awareness and knowledge of traditional customs will be irretrievably lost for humanity.

2 Material and Methods

Extensive field surveys to record the various uses of insects of the Adi tribe were carried out in three districts, namely East Siang, Upper Siang and Lower Dibang Valley in the north-east of Arunachal Pradesh. Two respective villages of different

Adi sub tribes were selected on the basis of their original parental village. A total of 18 villages were visited covering each of the subtribes' areas. The number of households per village visited was 80–200. At least three households inhabited by village elders and their families were visited per village. Recommendations by the headman or village elders to visit certain knowledgeable persons in another village were sometimes followed.

The surveys were based on focus group discussions, interviews during which a total of 20 persons aged between 45 and 70 years of age (12 male and 8 female) from each tribe were shown museum specimens or photographs of insects. For knowledge of insects used in traditional healing methods, idioms, myths etc. shamans or local priests were visited. They are believed to be the most knowledgeable persons in a village. The interviewed people were then asked simple questions in order to obtain information on the vernacular names of the edible or otherwise important insects, seasonal availabilities, and stages of insects consumed or used, mode of preparation, assumed therapeutic value, folklore related to insects and anything else deemed important in connection with the insect in question. As the knowledge of Hindi or English of the locals was often not great, our questions had to be simple and to the point. As one among the authors (KM) himself belonged to the same tribe, he could ask questions in the local dialect fluently and frankly, ensuring that maximum and deep doctrinal knowledge could be obtained and recorded.

3 Result and Discussion

The socio-cultural significance of insects (Nonaka 2005, 2009) manifests itself in many ways (Schimitschek 1968; Hogue 1987; Meyer-Rochow et al. 2008) and in the life and the culture of the Adi insects certainly play important roles. Although the largest number of species can be found in the food category (Fig. 1), insects are also used therapeutically and are referred to in songs, proverbs and sayings. They are components of festivals, myths, legends and beliefs in creation and they are invoked by sorcerers. Some are linked to death and evil spirits and are considered taboo. We shall now illuminate some of the most common associations between the Adi and their insects and will start with the local system of classifying and naming insects.

3.1 Nomenclature of Insects by Adi

The way an individual animal is named is a reflection of its general perception and utilization. The Adi have given insects their names on the basis of: 1. typical sounds the insects produce, 2. the habitat in which insects are mostly found, 3. outward appearance and behaviour and 4. traditional and mythical significance of particular insects (Table 1).

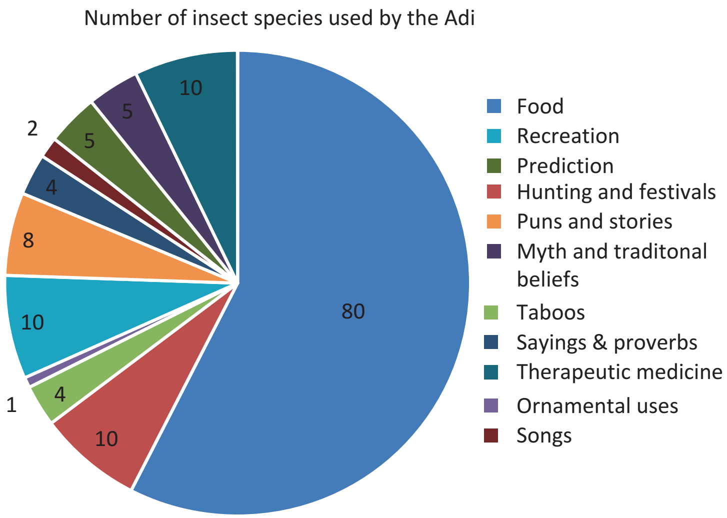


Fig. 1 Diagram showing cultural uses of insects by Adi Tribe

It has been observed that the use of the prefix "*ta*" is frequently used in connection with hymenopteran, orthopteran and dipteran, i.e., elegantly flying species. Further, the last syllable of an insect's name frequently appears to become used as a prefix in naming different but closely related species. For example, '*takom*' refers to insects in general, but '*komki*' is the praying mantis); similarly, '*taruk*' are ants generally, but *'rukkung'* and *'rukjampampi'* are weaver and black ants, respectively. Naming of different developmental stages is rather uncommon. However, all the larval stages of beetles (grub) are called *'takkin'*, and distinguished as *'among takkin'* (underground) and *'esing takkin'* (wood inhabiting). Maggots and caterpillars are commonly called '*tapum*', but the larvae of bees, ants, wasps (Hymenoptera) and nymphs of most Hemiptera are known as '*ao*' (baby).

3.2 Insects in Myths and Beliefs

Insects are intricately linked with spiritual aspects in the daily lives of the Adi, but not to the extent it was the case in ancient Egypt (Ward 1994). An Adi's most prestigious and treasured possession are its semi-domesticated bovids known as Mithun (*Bos frontalis*). Adis believe that humans and insects descended from a common ancestor and especially white ants and bees are mentioned in some of the Adis' mythological songs.

Insects are also mentioned in many stories of the Adis, who believe that an early ancestor of present day humans, known as '*Doying Bote*' had also been a keen observer of insects. For example, by killing an ant of a pest species, abundant in the paddies, the Doying Bote saved his future generations. Insects like praying mantis (local name *komki*), stick insects (local name *sikkom tanom*) and

Table 1 Adi nomenclature of commonly known insects and other arthropods with phonetic transcription and cultural use

Insect Arthropoda						
Order	**Family**	**Common name**	**Local name**	**Phonetic transcription**	**Basis of naming**	**Cultural use**
Ephemeroptera	All families	May fly	Tayo	Tajo	C	Appreciated for delicateness and fragility.
Odonata	All families	Dragon fly/ damsel fly	Papi-Tayo	Papi tajo	ND	1. Children play with them after binding a thread on their abdomen and let them fly around. 2. Heads and thorax are eaten raw 3. Nymphs edible
Phasmatodea	Phyllidae	Leaf insects	Anne takom	Anne takom	M	Believed that leaves have turned into insects.
	Phasmatidae	Stick insects	Sikkom Tanom	Sikkom Tanom	TB	Considered to be ghosts and spreading boils and diseases to humans.
Orthoptera	Acrididae	Grasshopper	Pemir	Pəmɨr	C	The Padam sub-tribe consider this insect to be unclean and believe that they copulate with earthworm, but for other sub-tribes this insect is a delicacy as food.
	Acrididae	Grasshopper	Urom Takom	Urom takom	TB	Considered to be a messenger of evil spirits, bringing different types of mild illness.
	Tettigonidae (unidentified sp.)	Katydid	Komserek	Komserek	TB	Believed that they have carried water for human beings.
	Tettigonidae (unidentified sp.)	Katydid	Pesi Mimum	Pəsi mimum	TB	Considered to be the sexiest insects. The design of the Ponung dress (a traditional dress) used during Solung festival of Adi is adapted from these insect
	Gryllotalpidae	Mole cricket	Jali-Jajong	dʒali dʒa:dʒoŋ	H	Considered that it ploughs the wet rice field

(continued)

Table 1 (continued)

Insect Arthropoda						
Order	**Family**	**Common name**	**Local name**	**Phonetic transcription**	**Basis of naming**	**Cultural use**
Hemiptera	Belostomatidae	Giant water bug	Asi taksi	Asi taksi	C	Considered to be cockroaches of the water, adults are used as food for humans.
	Cicadidae (unidentified sp.)	Cicada	Jajang	Dʒadʒaŋ	S	Their sound represents the onset of summer.
	Cicadidae (unidentified sp.)	Cicada	Goyeng	Goyeŋ	S	1. Believed that the sound produced by this insect assists jackfruit to ripen. 2. The presence of this insect causes shedding of hair in domestic pigs.
	Cimicidae	Bed bug	Taba	Taba	ND	Considered to be irritating insects, controlled by burning the place where they reside.
	Pentatomidae (unidentified sp.)	Stink bug	Sitong Tari	Sitoŋ tari	H	Used as bait for rodent hunting, highly appreciated as food.
	Pentatomidae (unidentified sp.)	Stink bug	Monam Tari	Monam Tari	H	Children are gifted with this insect after returning from jungle by their parents. The pronotum of this insect is pierced and a thread tied to it, and then children enjoy playing with it.
Mantodea	Mantoidae	Praying mantis	Komki	Komki	TB	Considered to be an agent of evil spirits. But its eggs are highly appreciated as food.
Isoptera	Termitidae (unidentified sp.)	Termite	Takmin	Takmin	ND	Considered that children will become deaf upon consuming them. Elders forbid children from eating them.
	Termitidae (unidentified sp.)	White ant	Tabin-dorin	Tabɨn-dorɨn	H	Foe of the tribal people for destructing homes made of wood.
Dermaptera	All families	Earwigs	Takom sepkong	Takom sepkoŋ	M	Considered to be the scorpion of insects because of the presence of forceps at end of abdomen; feared by people.

Neuroptera	All families	Antlion	Kutkung-yuyu	Kutkuŋ- juju	H	1.As the name indicates (Kutkung means below the floor of traditional houses in the dry soil) it is believed to be protector of the house. 2. Children used to play with the larva of these insects.
Lepidoptera	All families	Butterflies	Popir	Po:pir	M	Highly admired by the Adi, and often mentioned in their romantic songs and proverbs.
	All families	Moths	Gam popir	Ga:m po:pir	TB	Believed to bring good luck to people.
	All families (small size spp.)	Rice grain Moths	Aam Popir	Aa:m po:pir	H	Considered that rice grain, when too old, becomes converted into these insects.
Coleoptera	Anthribidae	Weevil	Situng papit	Situŋ pa:pit	H	Considered to be the lice of wood.
	Buprestidae	Jewel beetle	Monam Papit	Mo:nam Pa:pit	H	Highly admired for their deep coloration.
	Coccinelidae	Ladybird beetle	Keru papit	Keru pa:pit	M	Used as temporary ear plugs/rings for temporary (Keru means ear plug/ring in Adi).
	Elateridae	Click beetle	Tikna papit	Tɨkna pa:pit	C	Children play with this insect. The insect clicks when held by the thorax.
	Lampyridae	Firefly	Uksing	Uksiŋ	TB	Believed to be the eye of ghosts and also associated with the stories of Adi.
	Scarabaeidae	Cow dung beetle	Papit	Pa:pit	H	Considered to be very unclean because of their habit to remain in dung.
	Scarabaeidae	Rhinoceros beetle	Situng papit	Situŋ pa:pit	H	Used for fun and entertainment, such as insect fights.
	Cerambycidae	Long horned beetles	Gargit	Gargit	ND	People appreciate this insect for their strong body make up and biting capacity.

(continued)

Table 1 (continued)

Insect Arthropoda						
Order	**Family**	**Common name**	**Local name**	**Phonetic transcription**	**Basis of naming**	**Cultural use**
Diptera	Calliphoridae	Blowfly	Taying	Tayiŋ	C	Use in simile "As thin as a wing of a Blowfly". Souls of some dead people are transformed into this fly, but maggots are eaten.
	Conopidae	Beefly	Tangut	Taŋut	C	Often feared by the Adi as it resembles a bee.
	Culicidae	Mosquito	Tarusunggu	Taru suŋgu	C	Regarded a nuisance everywhere.
	Muscidae	Housefly	Ekum Tamit	Əkum tamit	H	Souls of some dead people are transformed into this fly, but maggots are eaten along with meats.
	Psychodidae	Sandfly	Tayuk	Ta:juk	H	A nuisance in rivers and jungles.
	Drosophilidae	Fruitfly	Ennok Tamit	ənnok tamit	H	During the brewing of local wine the presence of vast numbers of fruit flies indicates the total fermentation of the wine and readiness to be served/consumed.
	Tephritidae	Fly	Mitdum	Mitdum	H	Causes skin disease in humans. To get rid of this insect people smoke by using tobacco leaves or opium and as a result people get addicted to the drug.
Hymenoptera	Apidae	Honey bee	Tangut	Taŋut	T	Associated with the genesis of the Adi people.
	Apidae	Rock bee	Ngutne	ŋutnə	TB	Believed to be the mother of all bees.
	Formicidae	Black ant	Nane-kosol	Na:nə- kosol	C	Believed to reel cotton.
	Formicidae	Black ant	Rukjam	Rukdʒam	TB	Believed that it stings the person who eats burned/overcooked foods.
	Formicidae	Weaver ant	Rukkung	Rukkuŋ	T	Considered to be bad during harvesting of horticultural products.
	Scolidae	Hornet	Logong	Logoŋ	C	Feared by the Adi for their painful sting
	Vespidae	Wasp	Tangko bere	Taŋko bere	TB	Believed to be sisters of bees.
	Vespidae	Wasp	Yomi	Jo:mi	ND	The abandoned hives are used in shaping traditional swords and machetes.

Phthiraptera	Pediculidae	Human lice	Tik	Tɨk	H	Considered to be a hair and body pest. This insect helps in maintaining social relationships. In order to remove this insects from the body manually people delouse each other.
Non-insect Arthropoda						
Order	**Family**	**Common name**	**Local name**	**Phonetic**		**Remark**
Glomerida	Glomeridae	Pill millipedes	Kettum-balum	Kəttum-ba:lum		Believed that it stops urination if it is put in private parts (penis/vagina) of children. Thus, parents use this insect to scare children for bed-wetting.
Scorpiones	Scorpionidae	Scorpion	Sepkong	Sepkoŋ		Feared for their deadly sting.
Opiliones	Leiobunidae	Harvest man	Epom Makbo	əpom-makbo		Considered to be the bridegroom of Epom (ghost of forest and mountain). So, one does not touch them.
Araneae	All families	Spider	Mopi-tarom	Mopɨ-tarom		Considered to be protector of house/jungle.
Acari	Ixodidae	Tick	Tapi	Tapi		Feared for their bloodsucking habits.
Diplopoda	Spirostreptidae	Millipedes	Tabi-nanyi	Tabɨ-nanji		Believed to be the aunt of snakes and must be avoided.
Chilopoda	Lithobiidae	Centipedes	Situng sepkong	Situŋ sepkoŋ		Considered to be the scorpion of wood; to be avoided.

(Abbreviations: *C* behaviour, *H* habitat, *M* morphology, *ND* not defined, *S* sound, *T* taste, *TB* traditional belief) tettigonids (local name *urom takom*) (possibly insects generally), however, are usually considered to be representatives of ghosts and evil spirits and therefore children get easily scared of them and avoid touching them. If incidentally these insects appear in human dwellings, people assume that an evil spirit hides amongst them. Adi do, on the other hand, recognise and appreciate clumps of eggs of the praying mantis *Komki* and consume such eggs raw whenever they spot a cluster of them.

Stick insects (*sikkom-tanom*) symbolize evil spirits and the souls of the dead that dwell in graveyards. People believe that these insects spray invisible chemicals that are very harmful to humans and can even lead to a person's death if the person trespasses through the graveyard. Although the insects will not always attack and indeed such attacks are said to happen only occasionally, it is assumed that attacks can occur at any time without prior warning. Thus these insects can impart a fear psychosis in people who encounter them in graveyards. Because of this fear Adi graveyards are situated far away from inhabited local settlements and no-one dares to cross them or roam around in the graveyards.,

Tettigonids (*urom takom* meaning ghost insects) are considered to be horrible ghosts, believed to be responsible for stomach pains and other mild illnesses of the body. People assume that these insects are wanting to attack them, but are unable to say when. To be on the safe side, they therefore perform some spiritual ritual (that does not involve insects) aimed at driving away the evil spirit and to initiate healing if some attack is assumed to have taken place.

3.3 Belief System of Insects as Weather and Season Forecasters

Human beings, the Adi believe, could learn many aspects ranging from simple predictions to powerful natural phenomena including solutions to scientific questions from observing insects and their behaviour. For the traditional Adi society, insect behaviours are interwoven with culture and customs. Insects serve as indicators for the weather and the seasons. For instance, it is believed that if the bees swarm towards the east, the weather will be good and sunny; if, however, the swarm veers towards the west, rain is most likely to follow. The sound of cicadas (*goyeng*) indicates the ripening of the jackfruit and, thus, the onset of the summer season. The sound of some insects (often those of the stridulating type) indicates the possibility of sudden showers and prompts people to hurry home.

3.4 Insects in the Sayings and Proverbs

The saying "*Susueng e paseng ko ...pityang e jajangko*" translates to *"Troublesome, something worth less than a small rat …"*, refers to cicadas, which are not worth a war or to bother about. Through this proverb the Adi people wish to indicate that trouble makers (i.e., noisy cicadas) will not gain anything and that one should avoid them and strive for a better solution, Searching for the little house rat (*Mus musculus*) is a worthless exercise for the Adi. Likewise, war and hatred will achieve nothing symbolized by the hollow and empty body of the cicada, and therefore should be got rid of. The smallest rodents like *Mus musculus* are so small that they have no benefit for human beings as they are not even being consumed. Similarly, the body of a cicada seems empty and hollow and are useless as a food item. From any kinds of troublesome activities, hatred and war, people generally do not get benefits; instead problems ought to be resolved peacefully.

"Yiine tuglinge peyig gela , ali tugling e peyig lenkai" translates to "*As the head of a bee is coloured, so is the ripened grain"* This saying's English equivalent is "like father like son". The Adi believe that the maturing rice grains are the result of copulations with bees during the flowering seasons of paddy/rice. Adi people seem to have keenly observed the appearance of bees during times when flowers of the paddies are in bloom. They therefore must have believed that as children resemble their parents the colour of the ripening grain (pale yellow) resembling that of the colour of the head of a bee (pale yellow) indicated the close relationship between bee and rice grain.

"Shedi irboe takomko, melo irtunge taarukko" refers to the male deity (= shedi) thought to be descended from grasshoppers and to the female deity (= melo), descended from the ants. The Adi are familiar with every aspect of these insects' behaviours. They consider these and other insects as earthly companions, because insects are also seen as creations of same deities as human beings.

"Tarukke ledue kopele" refers to the apparently erratic "zigzagging" trails of ants. Adis traditionally do appreciate the ants' social life and behaviours and have noticed that despite their zigzag and less than straight paths that the ants travel, they always reach their destination. This is how Adis learn tolerance, patience and endurance from ants.

3.5 Insects in Connection with Songs and Music of the Adi

Adi people love to sing, but not everybody sings well, which is why on special occasions special songs are sung by expert singers. However, most songs are sung by just about anyone at any place, e.g., working in the field, during festivals and celebrations, while paddling along the way from home to field and back etc.

"Jajange alap kuasanai, dumpong solo pobin ko gela, ekong belo meyoko gela, among taleng pensam so denam denggong dope". In translation this song's words are: "If I were having wings like the cicada and I had a crown and a tail like a bird, I would fly away merrily wherever I wish in between this infinite sky and earth".

"Solung gidi ayekuem, gopung goyeng manyekuem, Asi korong tokko so, ngonyik ayang duyarye". In translation the words to this song are: "On the arrival of the Solung festival, when insects begin to chirp and sing along this flowing stream, our love to each other will remain forever".

The song "*Digin Diyu Riksu Tasik*" has 15 lines and it is here presented first in the Adi language and then in the translation into English:

1. *Digin Diyu riksu tasik*
2. *Dumboko soli-sotok daknam*
3. *Naneke kojing yok-mo*
4. *Bompit pili satoname*
5. *Milong pokbong gedang kai*
6. *Kok yop- pok gedang kai*
7. *Sirki go-yie rikme telo*
8. *Awai awai*
9. *Edung kola po-rung ya-mang*
10. *Ekkam kola panat yamang*
11. *Pipur pipure mandoku*
12. *Pakkom pakkome mandoku*
13. *Goyeng goyeng e mandoku*
14. *Jajang jajang e mandoku*
15. *Awai awai!*

1. *From above the Milky Way*
2. *While a male barking deer was swooping down*
3. *with the poison arrow head*
4. *shot upward to strike the deer,*
5. *then the deer jumped over and across the house*
6. *then the deer jumped over and across the hut*
7. *into the cultivated field.*
8. *Oh what a shame!*
9. *It could not earlier collect bamboo tubes*
10. *It could not earlier collect leaves.*
11. *The birds have started singing 'pipur pipur'*
12. *The birds have started singing 'pakkom pakbo'*
13. *The cicada started singing 'goyeng goyeng'*
14. *The beetle started singing 'jajang jajang'*
15. *Oh what a shame!*

3.6 Insects in the Short Stories of Adis

Stories are told generally by older people to their children or grandchildren for many reasons. For example, to induce children to sleep, to entertain children and mingle with them as it is Adi tradition that older relatives take care of small children, while active adults are at work, to provide moral teaching or transfer knowledge to the young generation.

Story 1: A long time ago, two friends, a bee and a firefly, travelled to a foreign land. While flying together the bee struck his nose and head on a rock and started producing a buzzing sound. Until today the bees produce this buzzing sound, but fireflies produced no sound when flying for they have light at night. The Adi believe that the buzzing sound produced by bees is due to the accident that happened a long time ago during travel to a foreign land.

Story 2: The Adi's deity "Kine- Nane" had sown the first grain and the grain began to grow up. Meanwhile, the bee that was a guest had visited the agricultural field. The great beauty of the mature grain attracted bee and the bee began to have a love affair with the blooming grain. The plant became pregnant and ripened. This story is in agreement with modern science that has identified the bee as the chief pollinator.

Story 3: Once upon a time while three friends, namely a sunbird, a deer and a bee stayed together, the bird said to its two friends: "Listen, my two friends, I have chewed 5 mango seeds within no time". On hearing this, the deer burst with laughter, so that its muzzle became rough and irregular. The bee on the other hand began to think and think deeply how a very small bird could possibly chew five such very large mango seeds. So the bee's belly became constricted and very narrow. The Adi believe that the muzzle of the deer became rough after this incident and the bee's belly became narrow and constricted.

3.7 The Role of Insects in Hunting Activities and in Festivals

Hunting and fishing as means of producing food stand in the same relation to the domestication of animals and as the gathering of wild fruits and roots stand to agriculture. Adi meat procurement may therefore be described as a gathering of animal food (Roy 1960). With the progress in the domestication of animals, hunting and fishing gradually changed from a means of livelihood into a form of entertainment. The Adi, it can be said, are in a state of transition and hunting can still be considered an economic activity of the Adi.

For hunting, or better trapping, of small animals like rats, squirrels and small birds, Adis usually employ automatic traps commonly known as 'etku', improvised and made up of local materials by the menfolk (Meyer-Rochow et al. 2015). In the time of the 'Unying Aran' festival children and women walk miles in order to collect specimens of the stinkbug *A. nepalensis* from river beds to be used as bait in the 'etku'. They prepare a paste from these bugs and along with locally made dough place it in the 'etku'. Rats and other small animals may be attracted to the trap by the pungent odour of the bait. Bamboo caterpillar, grasshoppers, katydids and beetles are also used, but mainly in order to catch fish and are stuck onto fish hooks as bait.

3.8 Insects in Recreation and Decoration

Besides the uses of insects for other purposes, Adis have used insects for recreation and decoration. The thorax part of "s*itung lunggu*" (situng = wood, lunggu = necklace), a coleopteran insect of the family Cerambicidae which is collected from dead wood of "*jhum*" (slash and burn) cultivation, is used in adorning necklaces of the Adi. Also, in the handle of machete, knife, sword and axe, the Adi used a waxy substance produced by ants. The wax has to be collected from the jungle and needs to be melted and applied to the surface of the handles with the help of fire. This wax gives a red colour to the handle and thus beautifies the tools as well.

The best gift for children once their parents return from the jungle are stink bugs (*Tessaratoma quadrata*) locally known as "*monam tari*" (monam = jungle, tari = bug). The pronotum of the bug is pierced and a thread is tied on it. The live bug then flies here and there and the children get excited and greatly enjoy playing with it.

Catching of butterflies and dragonflies is a common childhood amusement of the Adi. They remove the legs of a live butterfly and then set it free; enjoying the clumsy behaviour of the helpless butterfly. Small insects are also collected and fed to the ants, which the children then carefully observe. By watching how the ants deal with their prey collectively and the children learn that the ant's behaviour is community-based and that they attack in groups and take away the dead or semi-alive insects given to them co-operatively.

3.9 Entomophagy of Adi

Adis consume a great variety of insects throughout the year with particular species dominating during specific seasons, either due to their abundance or importance at such times (Fig. 2). The amounts of insects ingested and species collected depend on an insect's seasonal abundance and cultural significance and thus often varies between sub-tribes. The stink bug *Aspongopus nepalensis,* locally known as '*tari*' and mentioned already in connection with the Unying-Aran festival, is consumed to a higher degree in winter due to its more appreciable pungent taste at that time (Fig. 2). Larvae, pupae and often adults of bees, wasps and weaver ants are being consumed throughout the year.

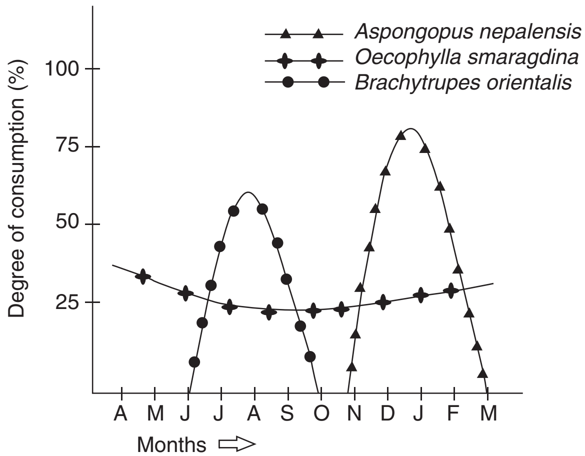


Fig. 2 Examples of seasonal uses of insect species

Insects are mostly collected from the wild in jungle, agricultural land, river beds etc. The appreciation of insects by the Komkar people is somewhat unique among all of the Adi sub-tribes as Komkars collect and consume more insects in terms of quality (i.e., species) and quantity than any other subtribe of the region. During harvesting times Komkar people always carry a locally made basket with them into which they put all the edible insects spotted by them during the whole day. In the evening after returning at home, they fry, boil or roast and consume them in this way or they prepare a chutney of them mixed with spicy ingredients to be eaten along with rice in their meal. For members of the Komkar sub-tribe insects represent a part of their regular/daily dietary intake, but for other Adi sub-tribes insects are more of s a side dish consumed whenever available. Their main form of preparation (and in fact that of most Adi: Table 2) involves grinding the live insects and turning them into a paste and into a chutney with ginger, garlic, salt and chillies roasted over the fire.

3.10 Insects in Traditional Health and Medicine

The reliance on nature by ethnic peoples throughout the world had inspired them to use insects as therapeutic agents and for medicinal purposes for themselves as well as for tamed animals (Meyer-Rochow 2017). Being no exception the closely related tribes of the Adi, namely the Nyishi and Galo tribes are known to have used at least of 16 species of insects in treatments of various ailments (Chakravorty et al. 2011). Another six Arunachal tribes. i.e., the Wancho, Nocte, Tangsa, Singpho, Deori and Changma have also been reported to use insects in therapeutic contexts (Chakravorty et al. 2013).

Members of the Adi community know how to employ diverse plant and animal products, including those of insects, to maintain mental and physical health. Adis believe that spirits, which assist in the transfiguration of a shaman/chief priest (locally called "*Miri*"), can dwell among the insects. A priest shows some unnatural behaviour when possessed by an unseen spirit that might stem from an insect. The Minyong sub-tribe therefore collects any kind of grasshopper and katydid whenever the transfiguration happens in the priest, so to make the spirit happy and to have an abundance of spirits for the shaman. The shaman in turn has the power to heal people from mental, spiritual and physical ailments. People who have been ferociously/viciously been attacked by bees may feel better once the beehive is set on fire and burnt to the ground. The people's tradition has it that that causes the evil spirits of the bees to being cast and released from the burning beehive.

A black ant of the family Formicidae and locally known as '*ruksol*' is collected by bare hands although it stings painfully. Collectors hold their breath when picking up one of these ants lest it shall not work as medicine. They make a powder of the ants and give a small amount (or small number of ants) along with some leaves to a wounded animal like for instance a mithun or a cow suffering from foot and mouth disease.

Honey is widely used in treating coughs, abdominal discomfort, headache etc. Moreover, the larvae of bees and wasp, given to a pregnant woman or lactating mother are meant to stimulate and enhance milk production. The common house

Table 2 Methods of preparation of some of the most commonly consumed edible insects by Adi tribals (+ yes; − no)

Procedures	*Aspongopus nep. epalllllnepalensis*	*Tessaratoma qua.*	*Lethocerus indd.*	*Nezara viridula*	*Tibicen pruinosus*	*Cyclochila virens*	*Chondacris rosea*	*Heiroglyphus sp.*	*Schistocerca sp.*	*Leptysma sp.*	*Brachytrypes sp.*	*Gryllotalpa sp.*	*Conocephalu sp.s*	*Vespa orientalis*	*Vespa sp.*	*Apis cerana*	*Oecophylla smar.*	*Apis dorsata*	*Anomala sp.*	*Xylotrupes gideon*	*Catharsius sp.*	*Monochamus ver.*	*Batocera roylei*	*Bombyx mori*	*Antheria assama*	*Wild caterpillars*
The insects are kept alive after collection.	+	+	+	+	+	+	+	+	+	+	+	+	+	−	−	−	−	−	−	+	−	−	−	+	+	+−
The whole body is eaten raw.	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	+
Eaten raw in the form of curry/chutney/paste.	+	+	+	−	−	−	−	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	+
Roasted in fire.	−	−	−	+	+	+	+	+	+	+	+	+	+	−	−	−	−	−	−	−	−	−	−	−	−	+
Eaten with other ingredients.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Appendages are removed.	+	+	+	−	−	−	−	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−
Head, gut, and intestine removed.	−	−	−	−	−	−	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−
Pre-boiled in water before final preparation.	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	+	−

1. Aspongopus nepalensis, 2. Tessaratoma quadrata, 3. Lethocerus indicus, 4. Nezara viridula, 5. Tibicen pruinosus, 6. Cyclochila virens, 7. Chondacris rosea, 8. Heiroglyphus sp., 9. Schistocerca sp., 10. Leptysma sp., 11. Brachytrypes sp., 12. Gryllotalpa sp., 13. Conocephalus sp., 14. Vespa orientalis, 15. Vespa sp., 16. Apis cerana, 17. Oecophylla smaragdina, 18. Apis dorsata, 19. Anomala sp.. 20. Xylotrupes gideon, 21. Catharsius sp., 22. Monochamus versteegi, 23. Batocera roylei, 24. Bombyx mori, 25. Antheria assama, 26.Wild caterpillars (various species, unidentified) cricket is given to pregnant women to bolster the nutritional requirements whenever hunting larger animals is getting tough. A paste made from live stink bugs has been used for treatment of flatulence and abdominal discomfort.

3.11 Insects Perceived as a Nuisance

In spite of the many remarkable services that insects provide (Borror et al. 1989; Losey and Vaughan 2006), they can also disturb the tribal life, since settlements are usually near the jungle and thus close to areas abundant with insects of all sorts. While running, riding a bicycle or motorcycle at dusk, insects may be so abundant that they strike the face and get into a driver's eyes, nose or mouth causing severe discomfort. Thus, they create a nuisance.

Upon clearing the forest during shifting cultivation, collecting of wild fruit or edible leaves from the jungles, whole swarms of bees (*Apis dorsata* and other bee species) as well as wasps may attack people and in the time of sowing, manual uprooting of weeds in paddy fields a great variety of ants pester, bite and sting the workers. During the period of harvesting wild and semi-cultivated fruits like jackfruit, mango, pear, and orange, weaver ants annoy the harvester as they voraciously attack anything and anybody that disturbs their nests.

In the hilly areas tiny dipteran insects of the family Deuterophlebiidae *("mit-dum"* in the Adi language) bite people and leave severe wounds with blood oozing out. To get rid of these insects, people smoke locally made hookah pipes or cigars. Mosquitoes, biting flies and sandflies vigorously bite anyone working in the jungle and are feared. Various types of insects such as moths, wasps, flies and even fireflies that enter local houses at night can cause annoyance and distraction and make the home untidy. Finally the sounds of some insects, e.g., flies, mosquitoes, wasps, bees and even cicadas can at times be so irritating that calling their disturbances mental harassment is justified as people exposed to such sounds can lose control and get into an angry and violent mood.

4 Conclusion

Procurement of wild animals, which includes insects, remains a routine for celebration of the Adi's three main festivals, which include Solung, Unying-Aran and Pime with pomp and gaiety. From an anthropological point of view, Marak and Kalita (2013) had described (although not fully precise) the hunting activities performed during and preceding these festivals of the Adi. The use of insects as food on these and other occasions boils down to two reasons: firstly, most of the insects are cheap and available (at least during some seasons of the year) and secondly, they are tasty. The question as to whether they are healthy or nutritious is of negligible importance when it comes to entomophagy. For therapeutic and other uses (summarized in Fig. 3) different motivations apply.

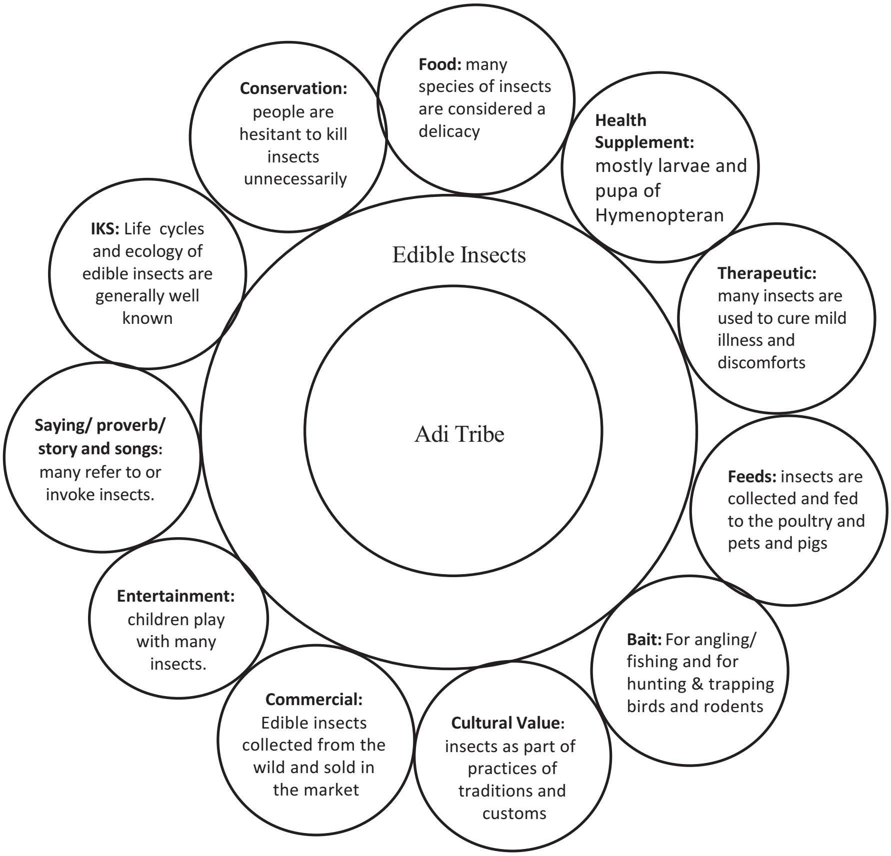


Fig. 3 This diagram is meant to show that the Adi tribe in the central circle is surrounded by insects that find year round use as an edible food source and are part of various activities as is mentioned in the smaller circles on the outside

Traditional sociocultural practices and taboos which exist in the society of the Adi as they do elsewhere (Meyer-Rochow 2009) can on the one hand be considered favourable for species conservations, as in a case described from Papua New Guinea (Sillitoe 2001). However, the legacy of gregarious hunting practices among the Adi for food and other utilizations, although important in the context of tribal coherence, is accompanied by a disguised declining of bio-diversity as has been shown the case for other areas in India (De and Kundu 2014).

Lack of ethical concerns among the tribal people and non-realization of the ecological services provided by the wildlife make them devour every wild creature they can lay their hands on – and that includes not just vertebrates, but insects as well. If the trend continues, it is likely that any form of wildlife close to or in the vicinity of tribal areas will suffer and ultimately shall get lost. Being mostly illiterate, logical perceptions on conservation of wildlife are non-existent among most members of the Adi people. It is therefore of the utmost importance to instil into the young generation of the Adi an awareness of the value of living organisms, a desire to maintain traditional uses of all wildlife and to safeguard that the organisms that have been part and parcel of the cultural identity of the Adi will still be around in the future to accompany the Adis' way of life.

Acknowledgements The authors are thankful to the University Grants Commission, New Delhi, for the financial support through a project grant by the Department of Science and Technology, New Delhi, to Professor J. Chakravorty and Mr. Karsing Megu as Junior Research Fellow and sponsorship for field study at various Adi-inhabited areas. Assistance from Rajiv Gandhi University, the Centre with Potential for Excellence in Biodiversity (CPEB) and cooperation received from the members of the Adi community in collecting the data is gratefully acknowledged by all three authors.

References

Borror DJ, Triplehorn CA, Johnson NE (1989) An introduction to the study of insects. Saunders College Publishers, Philadeplphia

Chakravorty J, Ghosh S, Meyer-Rochow VB (2011) Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (North-East India). J Ethnobiol Ethnomed 7:5. https://doi.org/10.1186/1746-4269-7-5

Chakravorty J, Ghosh S, Meyer-Rochow VB (2013) Comparative survey of entomophagy and entomotherapeutic practices in six tribes of eastern Arunachal Pradesh (India). J Ethnobiol Ethnomed 9:50. https://doi.org/10.1186/1746-4269-9-50

Chaudhuri SK (2013) The institutionalization of tribal religion, recasting the donyi-polomovement in Arunachal Pradesh. Asian Ethnol 72:259–277

De R, Kundu JK (2014) An ethnozoological study on the tribes of Jhargram. Sci Cult 80(7–8):229–231

Hogue CL (1987) Cultural entomology. Annu Rev Entomol 32:181–199

Losey JE, Vaughan M (2006) The economic value of ecological services provided by insects. BioScience 56:311–323

Marak Q, Kalita J (2013) Indigenous knowledge system associated with hunting among the Padams of Arunachal Pradesh, India. Cult Anthropol 9(2):309–317

Meyer-Rochow VB (2009) Food taboos: their origins and purposes. J Ethnobiol Ethnomed 5:18. https://doi.org/10.1186/1746-4269-5-18

Meyer-Rochow VB, Megu K, Chakravorty J (2015) Rats: if you can't beat them, eat them (tricks of the trade observed among the Adi and other North-East Indian tribals. J Ethnobiol Ethnomed 11:45. https://doi.org/10.1186/s13002-015-0034-2

Meyer-Rochow VB (2017) Therapeutic arthropods and other, largely terrestrial, folk-medicinally important invertebrates: a comparative survey and review. J Ethnobiol Ethnomed 13:9. https://doi.org/10.1186/s13002-017-0136-0

Meyer-Rochow VB, Nonaka K, Boulidam S (2008) More feared than revered: insects and their impact on human societies (with some specific data on the importance of entomophagy in a Laotian setting). Entomol Heute 20:3–25

Myer N, Muttermeier RA, Muttermeier CA, da Fonseca GAB, Kent J (2000) Biodiversity hot spots for conservation priorities. Nature 403:853–858

Nonaka K (2005) Ethnoentomology – insect eating and human-insect relationship. University of Tokyo Press, Tokyo

Nonaka K (2009) Mushi ha gochisou! [Enjoying insects as food]. Komine Shyoten, Tokyo
Olson DM, Dinerstein E (1998) The global 200: a representation approach to conserving the Earth's most biologically valuable ecoregions. Conserv Biol 12:502–515
Roy S (1960) Aspects of Padam-Minyong culture. North-East Frontier Agency, Shillong
Schimitschek E (1968) Insekten als Nahrung, in Brauchtum, Kult und Kultur. In: Helmcke J-G, Stark D, Wermuth H (eds) Handbuch der Zoologie – eine Naturgeschichte der Stämme des Tierreichs, Band 4. Akademie Verlag, Berlin, pp 1–62
Sillitoe P (2001) Hunting for conservation in the Papua New Guinea Highlands ethnos. J Anthropol 66(3):365–393
Subba TB, Ghosh GC (2003) The anthropology of North-East India. Orient Longman Private Ltd, New Delhi
Van Driem G (2001) Languages of the Himalayas: an ethnolinguistic handbook of the greater Himalayan region. Brill, Leiden, ISBN 978-90-04-12062-4
Ward WA (1994) Beetles in stone: the Egyptian scarab. Biblic Arachaeol 57(4):186–202

Edible Insects and Their Uses in North America; Past, Present and Future

Marianne Shockley, Julie Lesnik, Robert Nathan Allen, and Alicia Fonseca Muñoz

Abstract Insects have been an important part of food culture for many different places and peoples across North America's history. This chapter retraces the indigenous uses of insects as a food across the continent, through modern Mexico and into the present day movement to bring these ingredients into the culinary landscape of the United States of America and Canada. The authors provide an overview of the practices and uses of insects as food in both whole and traditional forms, and newer abstractions of the insects into consumer facing snack food products. In addition, the ways in which these startup farms and product makers are using insects for food are discussed, including facets such as crowdfunding, processing and marketing, as well as evidence from the culinary and celebrity worlds that entomophagy is gaining traction in North America.

1 Introduction

Insects have never been considered part of the traditional American diet, but the practice is not completely absent from North American history. The "American" diet we think of today is one of great European influence; prior to colonization, numerous diverse tribes of indigenous peoples inhabited the continent. For some of these groups, edible insects were an important part of their lives. Most of our understanding of how these insects were consumed comes from the recorded observations

M. Shockley (✉)
University of Georgia, Athens, GA, USA
e-mail: entomolo@uga.edu

J. Lesnik
Wayne State University, Detroit, MI, USA
e-mail: julie.lesnik@wayne.edu

R. N. Allen
Little Herds, Austin, TX, USA

A. F. Muñoz
Instituto Politecnico Nacional, Oaxaca, Mexico

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_4

of anthropologists as well as non-academics, such as explorers. The earliest accounts are especially biased, placing European values on the cultural norms of indigenous people. In these writings, indigenous people are described as primitive, savage, and animal-like (see Morgan 1877). The practice of eating insects therefore was either a part of this savagery, or only something done when no other food choices remained (Schrader et al. 2016).[1] Today, many people, such as chefs, entrepreneurs (Shockley et al. 2017), academics, and more, are working to promote insects as a healthy and sustainable food source and help get people past these stigmas. This chapter reviews insect eating across the continent of North America, with primary focus on continental United States and Canada. We begin with a history of indigenous use of edible insects, which is one that has been mostly lost post colonial settlement. We then look at a more recent history of the academic interest in edible insects beginning in the latter part of the twentieth century, and continue on to the resurgence of interest in the twenty-first century, assessing the current movement to get more people to eat insects and a projection of what the future holds.

2 Indigenous History of Insect Eating

Prevalence of insect eating is variable around the globe; one factor behind the pattern is that not all environments are conducive for producing edible insect options. The tropics offer the most biodiversity, and it is well documented that insect consumption is much more prevalent in tropical countries than others (Van Huis et al. 2013). As latitude increases away from the tropics, insect eating reduces (Lesnik 2017). For instance, all European countries are located at latitudes north of the subtropics, and for the first inhabitants of these areas, hunting was the only way to survive the harsh winters (Leonard 2003). Today, domesticated animals have replaced large game in most European diets, and this reliance on meat reduces the likelihood of insects being consumed since they have similar nutritional offerings.

2.1 Canada

In North America, ecozones vary greatly. Almost the entire country of Canada, like most of Europe, resides past the 45th parallel, which is the halfway point between the equator and the North Pole. The environments here typically undergo large seasonal temperature differences, and accounts of insect consumption by First Nations Peoples are limited. Caribou hunters, such as the Tłı̨chǫ (or Tlicho) of the Northwest Territories, ate warble fly larvae, which was a byproduct of their hunting (Felt 1918). The larval form of this parasitic fly species can often be found in abundance

[1] For a more in-depth review of North American edible that includes taxonomic designations, see: Schrader et al. (2016).

when butchering caribou. It is documented that the Tłı̨chǫ valued these larvae for their taste and would often leave them in place to develop further before eating them raw (Hearne and Tyrrell 1795; Russell 1898). In the east, the Wolastoqiyik (also known as Maliseet) of New Brunswick used black ants as a source of food and medicine (Schrader et al. 2016). Ants even made their way into the diets of some settlers, with reports of lumberjacks in Québec (and Maine in the U.S.) who would catch and eat carpenter ants (Schrader et al. 2016).

2.2 Mexico and Latin America

The country of Mexico straddles the Tropic of Cancer, placing it in the tropics and subtropics. Traditional Mexican cuisine is rich with edible insects, and in fact, Mexico is one of the world's leaders in insect consumption with over 300 known insect species commonly consumed (Ramos-Elorduy 2009; Jongema 2017). In the context of edible insects, Mexico is better classified as Mesoamerica or Latin America because of the vast climatic and cultural differences between this country and its northern neighbors.[2] However, Mexican culture has not gone without Western influence. Even in the state of Oaxaca, where chapulines (toasted grasshoppers) are celebrated as a symbol of Oaxacan identity (Thrussell 2016), by the late 1960s, there was growing tension surrounding foraged foodstuffs as they lacked prestige (Wilken 1970). Today, younger generations consider chapulines a traditional dish; something that is popular with the elderly and a symbol of rural life that may be useful in a moment of crisis, but mostly to be eaten as part of a celebration of culture (Cohen 2004; Grieshop 2006).

2.2.1 Diversity of Edible Insect Species

Mexico is a country characterized for being biologically rich and culturally diverse. Since ancient times, the practice of collecting insects for human consumption (entomophagy) was very common in many rural areas. Entomophagy in Mexico is believed to have been practiced before Spanish conquest (Christenson 2007). Native people used to collect the insects from the land and water. The tradition and preparation of insects have been kept alive in rural communities through many generations up to the present.

In Mexico, between 504 and 535 species of edible insects have been recorded (Ramos-Elorduy et al. 2006; Costa-Neto and Ramos-Elorduy 2006). Most of these species are collected from terrestrial ecosystems and few species from aquatic ecosystems. All these species are collected including different stages of their

[2] For a more thorough review of entomophagy in Mexico, see the works of Julieta Ramos-Elorduy. Also of note is volume 2(1) of Journal of Insects as Food and Feed, which is a special issue dedicated to Latin America.

biological development (eggs, larvae, nymphs and adults). Thus, in Mexico, 13 orders are reported: Coleoptera, Lepidoptera, Hemiptera, Diptera, Hymenoptera, Orthoptera, Homoptera, Ephemeroptera, Odonata, Trichoptera, Anoplura, Isoptera and Megaloptera (Ramos-elorduy and Viejo Montesinos 2007). Among the orders with greater consumption is Coleoptera, Himenoptera, Ortopteros and Lepidoptera.

The order Coleoptera Ramos-Elorduy and Pino Moreno (2004) reported 126 species in 18 states in Mexico. The most abundant family was Melolonthidae followed by Cerambycidae, Dytiscidae, and Passalidae. Families with most edible genera are Cerambycidae, Melolonthidae, Passalidae, Dytiscidae, and Tenebrionidae. Among some states in Mexico where edible insects have been reported are Chiapas, Oaxaca, Mexico, Hidalgo, Guerrero, Queretaro, Campeche, Guanajuato, Tabasco, Puebla, Jalisco and Michoacan (Ramos-Elorduy et al. 1997; Ramos-Elorduy and Pino 2006, 1998).

2.2.2 Entomophagy in Estado de Mexico

Estado de Mexico is one of the 31 Mexican states located in the center of the country next to Mexico city. In this state, there is a record of 104 species of edible insects (Ramos-Elorduy et al. 1998). The most consumed are Hymenoptera, Orthoptera, Hemiptera and Coleoptera (Ramos-Elorduy et al. 1998). Native people from Estado de Mexico practiced entomophagy even before the Spanish conquest. Nowadays, it is a common practice and commercialized by some companies. For example, one of the regions of the Estado de Mexico, specifically in Santo Domingo, Axapusco, is known for the collection of honey pot ants (*Myrmecystus mexicanus*). This kind on ants produce honey and are very attractive for consumption and commercialization because of its nutritional and medicinal properties (Ramos-Rostro et al. 2009).

2.2.3 Entomophagy in Oaxaca

Oaxaca is one of the states where insects are most consumed. It is a multicultural state rich in indigenous traditions, myths, customs, beliefs and ethnicities (Ramos-Elorduy et al. 1997). Insect consumption is very common in this state, the main insect orders reported so far are Anoplura, Diptera, Orthoptera, Hemiptera, Homoptera, Lepidoptera, Coleoptera and Hymenoptera (Ramos-Elorduy et al. 1997). Insects that are most consumed are chapulines (Orthoptera), maguey worms (Lepidoptera), chicatanas and escamoles (Hymenoptera) among others. Insects are sold in markets, restaurants, and companies. The top-selling insects are grasshoppers, followed by mescal worms and ant's eggs. In the market, the sellers (mostly women) mainly sell grasshoppers of different sizes and flavors (lemon, chile, and garlic) and maguey worms among others. The sale of insects is given by varying measuring units that have preference among different merchants (fist, pots, grams). As for the commercial companies, Inalim is a Oaxacan company that sells products at national and international level prepared with chapulines *Sphenarium purpurascens* and maguey worms. Some of its products are the sauce of chapulin with 12 flavors and salt of chile prepared with maguey worms, which can be accompanied by a mescal. On the other hand, restaurants usually have their menu based on foods prepared with chapulines such as mole, tlayudas, tamales and stuffed peppers among others. In times of rain, people go out to collect the chicatanas “flying fleas” or “flying ants” which are consumed mainly in sauces and mole. It is worth mentioning that chicatanas are considered a luxury dish, due to the high cost in the market.

2.3 United States of America

The United States represents the transition between these two very different climates. In the southeast, the climate is subtropical, in the southwest it is semi-arid or desert, the western seaboard is Mediterranean-like in climate, while the northeast and Midwest experience the great variation in seasonal temperatures associated with northern latitudes. Therefore, prevalence of edible insects varies greatly across these regions.

2.3.1 Great Basin

Insect consumption was most prevalent, or at least best documented, for Native Americans of the Great Basin region. This area west of the Rocky Mountains is a closed drainage basin that retains water and allows no outflow; therefore salts and other dissolved minerals accumulate in lakes such as the Great Salt Lake or Mono Lake (Hammer 1986). Insects, such as drowned grasshoppers and the pupae of shore flies, can be easily collected on the shores of these lakes while already being naturally salted (Sutton 1988; Madsen and Schmitt 1998; Ebeling 1986; Schrader et al. 2016). However, this is not the only way insects were consumed in the Great Basin. In their review of North American entomophagy, Schrader and colleagues offer these other examples for the region: June beetles being caught and fire roasted (Sutton 1988), swarms of Mormon crickets driven into trenches that were then set on fire (Egan and Egan 1917), carpenter ants collected, dried, and ground into flour (Steward 1943), and Pandora moth caterpillars being wrangled at the base of trees by way of dug trenches (Aldrich 1921).

Much of what we know about entomophagy in the Great Basin and other arid regions of California, Nevada, and Arizona, comes from archaeological contexts (Sutton 1995). Dry environments promote easier preservation of organic matter, so the likelihood of finding archaeological evidence of insect consumption is greater in these localities. Also, the topography of this region includes numerous caves, which were natural shelters for people, but also aided in the preservation of artifacts. Food caches containing grasshoppers have been uncovered from Mantles

Cave in northwest Colorado (Burgh and Scoggin 1948) and Crypt Cave in northwestern Nevada (Orr 1952). These dry and protected conditions are also suitable for recovering preserved human feces known as coprolites. At Dirty Shame Rockshelter in southwest Oregon, termites of the Reticulitermes genus made up 78.3% of one of the coprolites. At Bamert Cave in east-central California, crane flies made up 25% of a coprolite. In the Glen Canyon area in southern Utah, the amount of insect remains that show up in coprolites increases over time, although the authors state that they never formed a major component of the diet.

2.3.2 Southeast

In the southeast, the semitropical environment suggests that this region should be the most conducive to edible insects. However, there are only limited records. In Brickell's (1737) account of the natural history of North Carolina, he mentions that the "Indians" ate wasp larvae from the combs. Although the tribe is unnamed, it is possible they were Cherokee, and that Carr's (1951) account of the Cherokee digging yellowjacket larvae from their nests is relaying the same cultural practice. The humid environment of this region is not conducive to the preservation of organic materials like that of the Southwest; however, two cave sites with remarkable preservation give some insight to insect consumption. A mummified body found in a rockshelter in the Ozark Mountains preserved insect parts along with other food items in its feces contents (Wakefield and Dellinger 1936) and another mummy, along with additional coprolites, recovered from Salts Cave Kentucky contain small quantities of insect cuticle, indicating their consumption (Yarnell 1974).

2.3.3 Midwest and Northeast

There are accounts of the utilization of edible insects in the Midwest and Northeast, even though these environments may be considered less suitable for edible insects. The now extinct Rocky Mountain locust that inhabited the arid land to the east of the Rocky Mountains was consumed in great numbers by many indigenous peoples as far east as Iowa and the Dakotas until the early part of the twentieth century. The Assiniboine of the Northern Great Plains would round up swarming locusts into open pits for collection (Berenbaum 1996). Periodical cicadas, which emerge in large numbers every 17 years in the northern states of the eastern U.S., provide a feast when they are available. The earliest written account of people eating cicadas comes from a journal entry dated Sandel 1715 written by Reverend Andreas Sandel, rector of the Swedish congregation in Philadelphia, Pennsylvania. He describes how these "flies" emerge from the holes in the ground, and that pigs, poultry, and even some people ate them before they disappeared only a short while later. People today still take advantage of cicadas when they emerge; it is possible to find many different recipes for their preparation online. Use of this periodic resource is a rare example of an edible insect that transcends the lines drawn between indigenous and colonial culture. This may be a beacon of hope for the future of edible insects in the United States.

3 Entomophagy in the Twentieth Century

The "Godfather" of modern entomophagy in North America was the late Dr. Gene DeFoliart at the University of Wisconsin, Madison. One of DeFoliart's legacies includes *The Insects as Food* website is a reservoir of information and scholarly literature produced by DeFoliart from the 1970s through the 2000s (February, 2017). This website, currently housed at the University of Wisconsin, holds peer reviewed publications of Dr. DeFoliart, his colleagues and his graduate students as well as a working worldwide bibliography of all of the edible insects published in the academic literature to date. This online resource is invaluable for piecing together the edible insect and entomophagy literature and more precisely the individual species of edible insects that have been recorded in the scholarly literature to date. The Insects as Food website is, to date, the most comprehensive bridge of research from the early twentieth century to the modern era of the entomophagy movement.

3.1 Food Insects Research and Development Project

The Food Insects Research and Development Project (FIRDP) was organized at the University of Wisconsin in Madison in 1986, primarily as a set of objectives aimed at stimulating a wider awareness among food and agricultural scientists, government agencies, and the public that insects are a food resource that warrants serious investigation. The deeply rooted traditions of food insect use among many, if not most, ethnic cultures of non-European origin provide an existing base upon which to build-from the bottom up, as opposed to the usual direction of innovation from the top down (Defoliart 1989).

> Public reeducation is also being advanced by a proliferation of public events featuring or including edible insects, such as open houses or field days sponsored by zoos, nature centers, state fairs, museums, universities, and professional societies. Details on such events, many of which are held annually, can be found in the pages of The Food Insects Newsletter, which began publication in 1988 and has proven valuable as an international forum and networking mechanism for researchers, educators, and others having an interest in the subject. While the public information advances are important, even more important is the apparent foothold that the subject is gaining in the US educational system (Defoliart 1999).

3.2 Food Insects Newsletter

In 1988, North American entomophagy was localized as the academic newsletter "The Food Insects Newsletter," edited by DeFoliart at the University of Wisconsin. Dr. DeFoliart and a group of interested graduate students and colleagues submitted articles published three times a year, from 1988 until 1995. Each edition of the newsletter featured several different authors from North America and around the world. Some of the submissions featured incidents of entomophagy in early Native

American cultures. Others submissions were of recipes or events where edible insects were served. Upon Dr. DeFoliart's retirement the newsletter ceased. In its place was a informative website "Insect As Food," edited and managed by DeFoliart, entomologist Dr. Florence Dunkel (a previous graduate student of DeFoliart's) of Montana State University and Entomophagy advocate and historian David Gracer. Although new articles were not being submitted, Dr. DeFoliart utilized the expansion of technology and the internet to make all of the articles of the Food Insects Newsletter available online. By making this information freely available online, there seemed to be a rapid expansion of westerners knowledge of entomophagy. Prior to this, individuals had to know of and be subscribed to the Food Insects Newsletters, which were relegated to academia and delivered in a printed issues several times a year. With the offering of hundreds of edible insect related articles online, further interest in entomophagy expanded. In the 1980s and early 90s, entomophagy advocates in the United States such as David Gracer and David George Gordon, The Bug Chef, appeared more commonly in the mainstream media including newspapers, magazines, and television. Books like David George Gordon's "Eat-A-Bug Cookbook," became available for those curious about edible insects, along with "Man Eating Bugs," by Faith D'Aluisio and Peter Menzel, and "Creepy Crawly Cuisine; The Gourmet Guide To Edible Insects," by Dr. Julieta Ramos-Elorduy.

3.3 Modern Edible Insect Use in Mexico

In Mexico, the use of insects for cooking has increased through the last few decades, and the diversity of dishes made with insects makes them increasingly accepted in society. The use of insects in food in rural areas plays an important role in the nutrition and economy of many indigenous peoples, but in restaurants, the costs are higher and thus still prohibitive. Without established standards of best practice and precise regulations, there is potential for over-harvesting and exploitation of the wild insects. Already species like the Chicatana Ant are becoming endangered as natural habitats are lost to development and more wild-crafters over-harvest the insects. Thus, domestication practices will be critical to Mexico's edible insect industry.

4 Edible Insects in the Twenty-First Century

Early in the 2000s, Dr. Florence Dunkel reached out to fellow edible insect advocates and published a book of all of the editions of the Food Insects Newsletters, providing a crucial resource to researchers interested in entomophagy. In 2008 the Food Aid Organization of the United Nations hosted a conference, "Forest insects as food: humans bite back" in Chiang Mai, Thailand, attracting scientists from all over the world to present, learn, and share information about insects as food in different cultures, communities, and countries worldwide. In retrospect, this event was a likely catalyst for the current entomophagy movement that we are experiencing from 2013 to the time of writing, 2017. Several North American edible insect advocates and researchers presented at this conference, and the event spurred a resurgence in worldwide focus and a shift towards thinking of insects as a nutritious and environmentally friendly food source.

4.1 Academic Interest Accelerates in North America

In 2009, a researcher at the University of Georgia (co-author Marianne Shockley), was contacted by a group in Alabama that was interested in hosting an International Edible Insect Conference. The query from the conference host was to report on the status of entomophagy in higher education. Representatives consisting of world renowned edible insect researchers, advocates, academics, and representatives from the FAO and other governmental organizations met to showcase the status of edible insects globally. One particular presentation request directed at entomologists in the U.S. was to determine the status of entomophagy in American Higher Education. It was presented that although edible insects appear as a lecture topic in a course at various institutions across the U.S. there was not a single, stand-alone university course dedicated to entomophagy. Entomologists and other academics were just not teaching and sharing information in universities and colleges across the U.S. about entomophagy to the degree seen elsewhere; the worldwide entomophagy movement had not yet trickled into science departments in the U.S.

Later in 2010, a Program Symposium was included in the Entomological Society of America Annual Meeting in San Diego, CA. "Entomophagy Reconsidered: Current Status and Challenges, Potential Directions, and an Invitation to Entomologists". At this symposia, former students, colleagues, and advocates of Gene DeFoliart's edible insect research presented about the current status of entomophagy in the U.S.

4.2 Shifting Popular Perceptions to Value Insects

Despite the growing excitement within small cadres of academics, by 2010 the idea of eating insects was still strange to most people in Canada, the United States and large swaths of Mexico and Latin America, outside of reality TV challenges and gameshow stunts like Fear Factor and Survivor. Even though there is extensive historical evidence of the traditional use of insects as food in indigenous cultures across the Americas, the Western food culture had long ago forgotten about insects as food. The idea was at best a novelty but more often a cultural and psychological taboo; revolting to the average consumer.

In 2010 something changed. As if in tandem with broader public discourse about food safety, transparency, corporate accountability, nutrition and climate change, small groups of advocates and entrepreneurs across the continent realized they had to shift the conversation on entomophagy. The goal was to push the public perception of insects away from gross gag gifts and poor food of desperation, and towards recognition as a nutritious and exciting ingredient. These organizations and companies began touting the benefits of bugs in a whole new way, focusing on the environmental and nutritional benefits as source of pride.

While insects as a novelty item had been around for decades through candy companies like Hotlix, these products like scorpion lollipops, candy-coated ants and chocolate-covered crickets were sold almost exclusively as gag-gifts. These products offered no information on the nutritional and environmental benefits insects as a food could provide, and weren't positioned as a food item a consumer would actually incorporate into their diet on a regular basis.

4.2.1 Abstraction for Hesitant Western Consumers

This all changed when the idea of "cricket flour," was first popularized by World Entomophagy, a startup company founded in 2010 in the dorm-room of University of Georgia student Harman Singh Johar (a student of co-author Marianne Shockley). World Entomophagy was the first USA company to publicly market insects ingredients specifically for human consumption, selling mealworms, whole crickets and cricket powder (billed as "cricket flour," these terms were often used interchangeably until 2015) directly to consumers. World Entomophagy began with Johar rearing crickets in his closet as an entomology student, baking them, grinding them, packaging them and shipping them off to waiting customers. Over the next 2 years World Entomophagy grew, moved to Austin, Texas in 2013 and was acquired by Aspire Food Group in 2014.

4.2.2 First Consumer Products

In 2012, capitalizing on the potential of abstracting insects for hesitant western consumers, Salt Lake City based Chapul was the first company to offer a snack product, protein bars, made with "cricket flour," crickets dried and ground to a fine powder. (What was then called "cricket flour" is now referred to as "cricket powder" by most companies in the industry. Cricket Flour on the other hand now commonly refers to a baking flour blend, combining insect powders and other flours for an easy baking substitution) It took Chapul 8 months to secure a cricket supply and a commercial kitchen, refine their recipes and work with regulators to take their unconventional product to market. Launching on crowdfunding platform Kickstarter, Chapul's founder Pat Crowley raised $16,065 to begin production of the first line of cricket protein bars, which would soon become eponymous with the entomophagy movement's push into the public view. At this time, there was still very little understanding to how insects would be regulated as a food, as there was little regulatory precedent outside of the cochineal beetle used for red dyes, and the mention of insects in the maximum allowable defect limits the FDA specifies for processed foods. "Our product was a first-of-a-kind, so we had to provide lab test results that showed our cricket flour, and the food we were feeding the crickets, were safe for human consumption," Regarding their crowdfunding, "We were surprised at how much interest it got. We had donors from 13 countries," Chapul used took the crowdfunding success and started their web presence and online store and purchased ingredients in bulk for their initial manufacturing run of cricket protein bars.

4.3 From Academia to the Popular Imagination

In 2012, the FAO held an Expert Consultation "Assessing the Potential of Insects as Food and Feed in Assuring Food Security" in Rome Italy, with the support of the Government of the Netherlands. This expert consultation consisted of international experts and entrepreneurs from around the world, specializing in varying aspects of insect rearing, plant protection and food engineering, and resulted in lively discussions with FAO experts from different backgrounds and disciplines. Soon after, a follow-up storm of public media press ensued discussing the idea of entomophagy critically. Popular press publications went from a few publications a month to a few publications each week (Shockley et al. 2017).

Additional international conferences and collaborations continued to inspire, motivate, and inform edible insect and entomophagy research in North America. Following the 2013 Expert Consultation in Rome, the FAO produced a follow up publication, "Edible insects: future prospects for food and feed security," sparking an interest among English language media outlets and a groundswell of publications from the popular press. "Edible insects: future prospects for food and feed security," is the most downloaded document that the FAO has ever had, at more than 7 million public downloads. The FAO report identified three main reasons for promoting the eating of insects: insects are healthy (high zinc, iron, calcium and protein), insect harvesting is environmentally benign (reduced greenhouse gas emissions and less land), and workforce creation with insect harvesting (low-tech, low-capital). In August of 2013 an interdisciplinary conference, "Poeticizing the Urban Apparatus: Scenes of Innovation, Translating Entomophagy Panel" was hosted in New York City. Following the panel was a Future Food Salon (FFS) hosted by Alimentary Initiatives and the Culture of Cities Centre. Having hosted the first FFS in Toronto focused on edible insects earlier that year, Alimentary Initiatives hosted a third FFS with Little Herds in Austin, Texas in 2014 and a final FFS in Montreal in 2015.

4.4 Crowdfunding

In 2013, following Chapul's initial success in crowdfunding, startup Exo also took to crowdfunding with overwhelming support. The use of crowdfunding to launch an insect product would quickly become a mainstay of the industry, and was an interesting exception in the world of consumer packaged goods (CPGs). While many industries and food trends are started by large corporations and conglomerates that see potential profits, the edible insect industry was pushed into the mainstream by startups with nothing but passion and the public's support. At the time of writing, early 2017, no large food companies have acquired an insect product company, and no large companies have created products with insect ingredients (beyond products containing cochineal as a dye and the aforementioned novelty candies). Since 2012, there has been a steady increase in the number of successful crowdfunding campaigns launching new insect products to the market (Fig. 1), showing that the public supports the idea of insects as food with their purchasing power.

Timeline of Edible Insects Crowdfunding	
2012	Chapul, USA: Raised $16,065 from 372 backers
2013	Exo, USA: Raised $54,911 from 1,241 backers
2014	Six Foods (Chirps), USA: Raised $70,559 from 1,295 backers Hopper Foods, USA: Raised $34,523 from 479 backers
2015	Crickers, USA: Raised $33,250 from 406 backers Krik Nutrition, Canada: Raised $16,428 from 191 backers Coalo Valley Farms, USA: Raised $3,173 from 23 backers CritterBitters, USA: Raised $23,627 from 438 backers (w/30hrs left) *CroBar, UK: Raised $10,227 from 111 backers* Crowbar's Jungle Bar, Iceland (produced and distributed in USA/Canada): Raised $27,806 from 23 backers Megan Curry's #BugWall, USA: Raised $2,051 from 29 backers
2016	Livin Farms Hive, USA and Hong Kong: Raised $145,429 from 830 backers Eat Grub Bar, UK: Raised $13,032 from 116 backers EntoBento, USA: Raised $16,001 from 225 backers Bugs On The Menu, Canada: Raised $2,044 from 49 backers The Gateway Bug, USA: Raised $19,855 from 232 backers *Butterfly Skye's VitaBug, Australia: Raised $3,282 from 27 backers* OneHop Kitchen, Canada: Raised $6,376 from 134 backers MealFlours, USA and Guatemala: Raised $16,120 from 244 backers Little Herds, USA: Raised $10,597 from 111 backers *Jimini's, France: Raised $23,651 from 346 backers* *Sens Bar, Germany: Raised $13,888 from 290 backers* Sidiki Sow, Canada: Raised $9,908 from 68 backers Lithic Nutrition, USA: Raised $12,160 from $169 backers
Total North American crowdfunding through 2016: $520,983	

Fig. 1 Crowdfunding; amounts raised and number of backers for North American companies through 2016 (companies outside of North America denoted in Italics and not included in the total)

4.5 From Ideas to Production

Continuing this global momentum, in 2014 the "Insects To Feed The World" conference was organized in collaboration between Wageningen University and the FAO, and was held in Wageningen, the Netherlands. The conference brought together the largest assembly to date of Insects for Food and Feed stakeholders from all over the world to consider key aspects of collection, production, processing, nutrition, marketing and consumption related to insects in a global multi-stakeholder dialogue. The conference marked an important step towards mobilizing the potential of insects as human food and animal feed to contribute to global food security and in particular to exchange information on the feasibility of mass rearing of insects to increase the availability of animal proteins in a more sustainable way. Several North American edible insect companies and researchers were in attendance.

Following the 2014 conference in the Netherlands, the first North American conference dedicated to edible insects, the "Eating Innovation Conference: the art, culture, science and business of entomophagy" was held at the Montreal Space for Life Botanical Garden and the Montreal Insectarium. This conference was attended by more than a hundred participants engaged in numerous disciplines within the overarching field of edible insects. Organizers hosted The Big Bang Bug Banquet, featured a nine course insect themed meal with accompanying insect infused drink selections prepared in part by chef Cookie Martinez.

In addition to interdisciplinary conferences hosted in the United States and Canada, annual symposia have been hosted at the Entomological Society of America (ESA) Annual Meetings, including ESA 2014 in Portland, Oregon - Insects as Sustainable and Innovative Sources of Food and Feed Production; ESA 2015 in Minneapolis, Minnesota - Synergies in entomophagy: Taking insect eating to the next level; 25th International Congress of Entomology in conjunction with the ESA Meeting 2016 in Orlando, Florida - An Emerging Food Supply: Edible Insects; and the upcoming ESA 2017 in Denver, Colorado - Insects: It's what's for dinner.

4.6 2016, Year of the Cricket

The first stand-alone academic conference devoted to Insects as Food and Feed in the United States was held in Detroit, Michigan in May, 2016. The Eating Insects Detroit Conference highlighted the current status of entomophagy and featured North American as well as international presenters and an insect dinner in conjunction with startup Detroit Ento. Edible insect expert panelists and keynote speakers gathered for 3 days of seminars, panels, presentations, group discussion and breakout sessions. This conference was the first time many of the North American stakeholders met in person, and was considered a resounding success by attendees as the first conference of its kind in the USA. Keynote speaker Paul Vantomme, recently retired from the FAO and co-author of the 2013 report on edible insects, proclaimed it to be one of the best conferences he had ever been to. This conference was also the site of the founding meeting of the North American Coalition for Insect Agriculture (NACIA).

4.7 *Entomophagy's First American Trade Association*

The North American Coalition for Insect Agriculture (NACIA) is the first American trade organization dedicated to insects as food and feed and was created in part due to the suggestions of Sonny Ramaswamy, head of the National Institute of Food and Agriculture at the United States Department of Agriculture. Founded by five entomophagy advocates, including co-authors Dr. Shockley and Mr. Allen, the NACIA was designed to be an inclusive and representative association for the fledgling industry. The NACIA held elections open to the public in the fall of 2016 and convened their first Board of Directors at the start of 2017, representing the Research, Business, Education and Regulatory aspects of both Food and Feed insects. The initial Board was comprised of many industry stakeholders, including:

Dr. Marianne Shockley (UGA), Alex Klonick, Amanda Bushell, Darren Goldin (Entomo Farms), Dr. Jeff Tomberlin (A&M), Cheryl Preyer (EnviroFlight), Ikju Park (Bitwater Farms), Travis Dorsey (Bitwater Farms), Robert Nathan Allen (Little Herds), Eli Cadesky (C-Fu Foods, One Hop Kitchen), Jakub Dzamba (Third Millennium Farming) and Julianne Kopf (BugEater Foods).

As an academic and researcher navigating the scientific literature and professional conferences, this author's experience (Dr. Shockley) with this emerging industry was very different than the experiences of the for-profit startups and farms. There seemed to be consistent confusion with local, state and federal health inspectors and agencies in the area of insects as food. Health inspectors are accustomed to identifying insects as pest, nuisance, and defect problems, not being confronted with them as a whole food ingredient. When members of the Insects for Food and Feed Industry collaborated at meetings, barriers and challenges were often points of discussion and sometimes contention, even disappointment. Professionals were expressing and sharing the challenges they had experienced at the local, state, federal and sometimes international level with agents not understanding their business, insects as the primary food ingredient, health and safety standards or protocols. The mission of the NACIA is to be a unified voice for the emerging insects as food and feed industry in North America.

5 Farming

Prior to 2012, no farms in North America grew insects specifically for food. There were however many farms growing insects, especially crickets and mealworms, for use as feed to pets and fishing bait. This provided a template for domestication that many startups began to refine. Despite this rudimentary template, many of the USA and Canadian insect farms have been heavily focused on automation, as labor costs are still seen as prohibitively high. Updating the practices inherited from the pet-feed insect industry by incorporating robotics, mechanization and automation into the system, as well as sensor technology and data aggregation allows these farms to iterate quickly towards the insect farms of the future. As trailblazers like Next Millennium Farms (now Entomo Farms) in Canada and Big Cricket Farms in the USA began to farm insects for food, more entrepreneurs around the continent followed suit and began small farming operations. These farms have primarily worked with the Common house cricket (*Acheta domesticus*) and the Banded cricket (Gryllodes sigillatus). In 2014 Aspire Food Group was the first company in the USA to both farm insects for human consumption and process them into ingredients like cricket powder (Called Aketta Cricket Flour) at their pilot USA farm in Austin, Texas. In 2016, industry giant and established pet-feed cricket farm Armstrong's Cricket Farm announced that they will be converting a small portion of their overall operation to crickets farmed for human consumption, signaling a sea change for other long-time pet-feed insect farms. While Organic Certification in either Canada or USA was initially thought to be insurmountable based on feedback from multiple Organic certification agencies, in 2015 Entomo Farms was the first food insect farm to receive Organic Certification (as well as Gluten-Free Certification) from EcoCert, an international Organic certifier, further establishing expectations and possibilities for consumers and farmers to come.

During this period, 2012–2017 (Fig. 2), there were only a handful of startup insect farms in Mexico working on the domestication of traditionally consumed

As of early 2017, active Food Insect farms in North America include, but are not limited to:

- Entomo Farms
- Tiny Farms
- Rocky Mountain Micro Ranch
- Iowa Cricket Farm
- Aspire Food Group DBA as Aketta
- Ozark Fiddler Farm
- Tomorrow's Harvest
- Seginus Farms
- Cowboy Cricket Farms
- Poda Foods
- *Detroit Ento
- *Big Cricket Farms
- *Coalo Valley Farms
- **Rainbow Mealworms
- **Armstrong Cricket Farm
- **Reeve's Cricket Farm

* Market status unconfirmed at time of writing
** Primarily Feed Insects, but entering Food Insects space

Fig. 2 North American farms actively growing and marketing insects for food as of 2017 insects, none of which have been successful to these author's knowledge. There is however a robust network of semi-cultivators and wild-harvesters who supply a wide variety of insects, especially chapulines grasshoppers and red agave worms, to chefs, product makers and individual consumers alike. The farming of greater mealworms, lesser mealworms, buffalo worms and super-worms for human consumption has not been adopted in North America beyond, to a small degree, Entomo Farms in Canada and Rocky Mountain Micro Ranch, Don Bugito and Rainbow Mealworms in the USA (Rainbow Mealworms farms insects primarily for pet-feed).

5.1 Crickets Over Mealworms

One of the most interesting differences between the North American entomophagy movement and the European counterpart is the preference of crickets over mealworms. It could be that "mealworm," contains the word "worm," and American and Canadian consumers have more negative reactions to the word "worm," than they do "cricket." It could also be that there was an established industry of crickets farmed for fishing bait and pet feed that provided a template for the first American and Canadian farmers to easily adopt when choosing their first insect to farm. More research could be done looking at the data from online searches and social media mentions to see if there's a clearer reason why crickets seem to, for now at least, dominate both the spotlight and the funding sources. Unfortunately we could find no studies addressing the prevalence of crickets in the North American edible insect market at the time of writing.

6 Common Processing Methods

There have been three main processes seen in the North American entomophagy industry for turning raw insects into insect ingredients: Roast and Grind; Slurry, Spray and Dehydrate; and Other.

6.1 Dry Roasting and Grinding

First piloted by early startups like World Entomophagy and Next Millennium Farms (Now Entomo Farms), this process is low impact and easily replicated from large-scale down to the home kitchen. Raw, usually frozen, whole insects are washed and cleaned, then dry roasted in an oven. Industrial convection ovens are often used, but other roasting devices like coffee roasters have been used as well. Once the insects are dried and crispy, they can easily be ground into a fine powder. The advantages here are the initial cost in machinery, which is low, and a smaller energy usage. The roasting creates a rich brown color in the powder and also brings out the nutty aromas and flavors commonly associated with cricket flour, or powder.

6.2 Slurry, Spray Dry, Dehydrate

Piloted by All Things Bugs (now GrioPro), this method takes the raw insects and combines them with water in a machine used to slurry the insects. The insect slurry is then sprayed as a fine mist onto trays that can be dehydrated, leaving a very fine powder as the final product. While this process is more energy-intensive, it does have the advantage of producing incredibly fine grains, and the powder tends to be more water soluble. These powders are typically more taste and aroma neutral, and are usually much lighter, almost white in color.

6.3 Other

Most recently in 2016, C-Fu Foods has been their piloting patent-pending processes to extract and restructure insect proteins into versatile food ingredients, like soluble protein powders for beverages and textured insect proteins for meat analogues. They have also piloted the use of their textured insect proteins as egg or dairy replacements in baking and food processing applications.

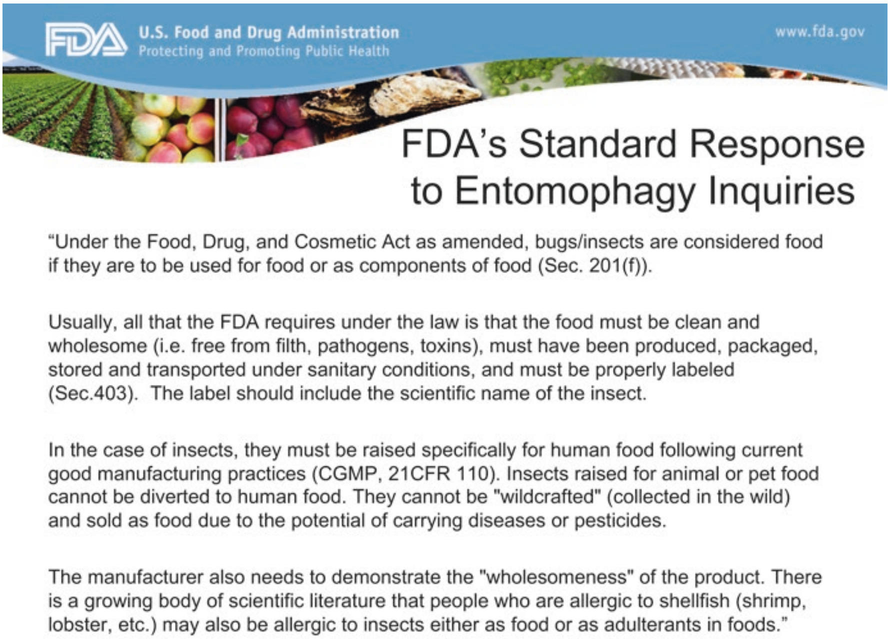
Other companies are working on separation processes to isolate the proteins, fats and chitin out from the raw insects for further specific uses in food, dietary supplements, pharmaceuticals and cosmetics.

7 Regulations, Investments and Marketing Trends

In order for this industry to grow successfully, many logistical hurdles are still being addressed. Without clear regulations, infrastructure investment is hesitant and risk-averse. Without investment into production and processing, insect ingredient costs remain high and research is limited. Finally, without regulatory clarity and investment for production, any positive marketing trends regarding perceptions of insect products cannot be capitalized upon.

7.1 Regulatory Landscape

While the growing industry was actively in communication with the USA's Food and Drug Administration (FDA), United States Department of Agriculture (USDA) and Health Canada (Canadian Food and Drugs safety authority) about



U.S. Food and Drug Administration
Protecting and Promoting Public Health
www.fda.gov

FDA's Standard Response to Entomophagy Inquiries

"Under the Food, Drug, and Cosmetic Act as amended, bugs/insects are considered food if they are to be used for food or as components of food (Sec. 201(f)).

Usually, all that the FDA requires under the law is that the food must be clean and wholesome (i.e. free from filth, pathogens, toxins), must have been produced, packaged, stored and transported under sanitary conditions, and must be properly labeled (Sec.403). The label should include the scientific name of the insect.

In the case of insects, they must be raised specifically for human food following current good manufacturing practices (CGMP, 21CFR 110). Insects raised for animal or pet food cannot be diverted to human food. They cannot be "wildcrafted" (collected in the wild) and sold as food due to the potential of carrying diseases or pesticides.

The manufacturer also needs to demonstrate the "wholesomeness" of the product. There is a growing body of scientific literature that people who are allergic to shellfish (shrimp, lobster, etc.) may also be allergic to insects either as food or as adulterants in foods."

Fig. 3 Standard response from the United States Food and Drug Administration regarding the use of insects marketed as a food (2013)

regulatory compliance and product safety as early as 2010, at that time there was little practical understanding of how insects could or should be regulated as a food in Canada and the US. In 2013 a small group of American insect farmers and insect product makers secured the first clear guidance from the FDA (Fig. 3), outlining what steps could be taken to have a safe and wholesome insect food product. Notably, the document specified that insect marketed for human consumption must be farmed specifically for human consumption; that insect food products must be processed, packaged and transported in accordance with current good manufacturing practices (cGMP); and must include a warning label for crustacean or shellfish allergies for consumer safety. This was key for the industry to align expectations of what constituted a "Human consumption-grade insect," and to have a clearer example of regulatory compliance with which to work from. For the next 2 years, many in the industry worked under the impression that insects would eventually have to be approved as Generally Recognized As Safe (GRAS) by the FDA to become a more mainstream product, as well as to secure key investments and distribution partnerships reticent to work with insects without clearer regulatory guidelines. However, in her 2016 Food Navigator story about edible insects, "Edible Insects: Beyond the Novelty Factor," Elaine Watson interviewed an FDA spokesperson who encapsulated the discussion even more succinctly, stating that insects, if they are farmed and processed as food, are food. They also stated that manufacturers using whole insects or milled powders made from whole insects would not be required to go through the GRAS process provided they comply with the pre-market provisions of the Food, Drug and Cosmetics act. At this point Health Canada has also provided clear guidance on pre-market provisions to insect product makers for selling insect products to consumers.

7.2 Investments in the Food Insects Industry

As of January 2017, several insect CPGs have gone beyond crowdfunding, and raised successful funding rounds from VC and Angel Investors. Chapul was the first company to be funded, when a 2014 appearance on the popular TV show Shark Tank (season 5, episode 21) secured serial investor Mark Cuban's investment of $50,000 into the company. That same year, Exo received initial Seed Funding through serial investor Tim Ferriss. (http://fortune.com/2014/07/18/bugs-in-your-protein-bar-are-edible-insects-the-next-food-craze/). In 2015, Entomo Farms in Canada raised $1million in a Series A from venture capital investors Hedgewood. Also in 2015, Bitty Foods raised $1.2 million in Seed Funding from Florence Group and Arielle Zuckerberg (sister of Facebook founder Mark Zuckerberg) and Tiny Farms raised an undisclosed amount of funding from Arielle Zuckerberg, Investors Circle, and former Bain & Company consultant Drew Fink. In 2016, Exo closed a Series A funding round of $4million with investors from AccelFoods, the Collaborative Fund, Tim Ferriss, endurance athlete Amelia Boone and celebrity rapper Nas. (https://www.entrepreneur.com/article/271951) As of the time of writing, Chirps Chips recently appeared on Shark Tank in January 2017, securing a $100,000 investment from Mark Cuban. Numerous companies have received grant funding from the USDA, including All Things Bugs (now GrioPro), who also secured initial funding through The Bill and Melinda Gates Foundations, though continued funding was declined. Most recently in 2016 BugEater Foods in Nebraska received a USDA grant to explore using insect ingredients in staple foods like pastas and noodles. Additionally, many companies have also won pitch competitions or been part of accelerator or incubator programs garnering prizes in funding and resources to help continue their work.

7.3 Market Trends

While the majority of insect based food products are still only available direct-to-consumer through websites, more companies have been able to secure distribution through online aggregation channels and physical retail locations since 2014 (Fig. 4). Many products can now be found through online giants like Amazon and insect food aggregators like EntoMarket, and the more established consumer product brands like Chapul, Exo, Bitty Foods and Chirps, as well as insect

North American Companies With Insect-Based Food Products On The Market (2017)

- Aspire Food Group (USA) DBA as Aketta
- Bitty Foods (USA)
- C-Fu Foods (Canada) DBA as One Hop Kitchen
- Chapul (USA)
- Cowboy Cricket Farm (USA)
- Craft Crickets (USA)
- CricketFlours (USA)
- Crik Nutrition (Canada)
- Critter Bitters (USA)
- Don Bugito (USA)
- Entomo Farms (Canada)
- EntoMarket DBA as EntoVita (USA)
- Exo (USA)
- Hotlix (USA)
- Incredible Foods (USA)
- Jurassic Snacks (USA)
- Gran Mitla (Mexico)
- Lithic Nutrition (USA)
- Merci Mercado (Mexico) DBA as Mercado Mio
- Naak Bar (Canada)
- Ozark Fiddler Farm (USA)
- Rocky Mountain Micro Ranch (USA)
- Sal De Aqui (Mexico)
- Seek Foods (USA)
- Seginus Farms (USA)
- Six Foods (USA) DBA as Chirps
- Tomorrow's Harvest Farms (USA)
- Uka Proteine (Canada)

Fig. 4 North American companies marketing insect products to consumers

ingredient brands like Entomo Farms, are making their way into grocery store shelves. Insect products can now be found in grocery and natural food chains like Sprouts Farmers Market, Mom's Organics, Wegman's, Vitamin Cottage/Natural Grocers and Publix Super Markets (Gustafson 2016).

In 2016, CEO of Pepsi Co. Indra Nooyi stated:

> "[Experts] said the hottest thing is eating crickets. I am not talking about the game cricket, I am talking about crickets! In chips. And I am a vegetarian, I am not eating any cricket chips. But they said if you want a high protein source, there is a series of products being launched with crickets," Nooyi stated. "One year, three year, five year, ten year: we have different people looking at different horizons, because if you believe in the ten year horizons and what we are seeing, some of the weirdest food and beverage habits are showing up." (Troitino 2016)

8 Media and Public Exposure

These startups didn't go unnoticed by the popular media either. There has recently been a massive shift in the way the press positions edible insects as a potential part of fixing our broken food system. Beginning in 2012, but increasing exponentially after the 2013 report "Insects to Feed the World," report by the FAO, prominent publications in print, radio, TV and online media have recognized the potential for insects to feed a growing population, not as a stunt or gag, but as a potential resource that's been ignored. The phrase "Edible Insects" was found in 728 news articles in 2010 and rose to 6070 articles in 2016. The term "Entomophagy" rose from 34 news articles in 2010 to 1230 articles in 2016 (Shockley et al. 2017). Numerous organizations and individuals promote education and outreach to the public around edible insects, including University student organizations like the University of Georgia Athens BugDawgs; nonprofits and educators like Little Herds, MealFlours, Ento Education, educator James Ricci, Daniella Martin's Girl Meets Bug blog; educational resources like Megan Curry's Open Source "Ento.Ed," middleschool mealworm farming curriculum; and Don Peavy's "Buggin' Out with ChefPV," kids education YouTube video series.

8.1 Chefs Lend Credibility

As more people began to be curious about eating insects, chefs who had been serving insects began to receive a share of the spotlight. When people eat at these restaurants, they know and trust that the chef will make the food delicious, and are more receptive to insect cuisine when it's on the menu. Chefs are also taking insect ingredients and using them in innovative and exciting new ways, transcribing the mysteries of how to best use insect ingredients for future home cooks. A great example is Chef Jose Andres, whose Oyamel has been serving chapulines tacos in Washington DC for years, priming the palates of tomorrow in a notably respected setting. Another example is from Austin, Texas where chef Charles Zhou of Barley Swine, known for their fermentation and pickling, has fermented crickets instead of soybeans to create a soy-less, umami-rich and earthy cricket-miso. Other examples include La Condesa and Dai Due in Austin; Linger in Denver; Sticky Rice in Chicago; Typhoon in Santa Monica; Sushi Mazi in Portland; Toloache, Mezcal and Black Ant in New York; El Rey and La Mezcaleria in Vancouver; El Catrin and Cookie Martinez in Toronto; El Cardenal, Azul Condesa or Pujol in Mexico City.

8.2 Celebrities Make Eating Bugs Cool

In the last 5 years the edible insect industry has seen a growing number of popular personalities, like athletes, actors/actresses, musicians, thought-leaders and public figures making public declarations about the benefits of eating insects. Prior to that, many entomophagy advocates like David George Gordon (aka The Bug Chef), David Gracer and Florence Dunkel had shared edible insects with talk show hosts such as The Tonight Show with David Letterman and The Colbert Report with Stephen Colbert. As more public figures try their first bugs, or even openly embrace adding insects to our diets, the public at large is becoming more receptive to the idea. This is not surprising, as many celebrities are seen as aspirational figures, desirable of emulation; if someone I admire and aspire to be like is open to eating insects, maybe I should give it a try too. Musician Questlove showcases insects as a food ingredient in his 2016 book, "Something to Food About." Actor and former American football player Terry Crews features in a 2016 Buzzfeed video about cricket protein shakes, claiming "That's the best protein in the world!" Former President of the United States of America, Barack Obama, even discussed eating insects as a small boy in Indonesia in his book, "Letters From My Father." Other prominent celebrities, musicians and athletes who have tried edible insects as of early 2017 include: Actors/Actresses Salma Hayek, Don Cheadle, Angelina Jolie, Ellen Degeneres, Christian Slater, Tituss Burgess and Anna Fariss, as well as singer Katy Perry, rapper Nas, endurance athlete Amelia Boone, Los Angeles Lakers Basketball player Metta World Peace and many more.

8.3 Getting Past the Ick Factor

Many American and Canadian consumers still have negative reactions towards the idea of entomophagy. Many of the advocates for edible insects use existing examples of Western food trends changing to justify the idea that insects will eventually be a normal food for people all across North America. Sushi is usually the prime example, with lobster, offal, Chinese food, kale and quinoa also used as examples of changing dietary preferences. Many educators, this co-author included (Allen), such as teachers, professors, museums, universities and nonprofit organizations like Little Herds have proposed that by introducing children to insect cuisine at a young age, those children grow up without the cultural taboo strongly entrenched, and are more open to entomophagy. This is purely based on anecdotal evidence from stakeholders and educators in the edible insects industry working in communication and outreach roles. Unfortunately, at the time of writing, no studies on children's "ick factor" related to edible insects could be found. Younger generations are also more receptive to new and unusual foods, and are usually more receptive to the idea of eating insects than older generations. As entomophagy continues to garner positive exposure in the media, more destination restaurants or acclaimed chefs serve them and more diverse products continue to gain market traction, the overall public perception will continue to shift towards acceptance and normalization.

9 Edible Insects in the Future

In early 2017 the Seattle Mariners baseball stadium began serving chapulines grasshoppers through a concession stand run by local restaurant, Poquito. For four nights in a row the stadium sold out of chapulines, creating much fanfare on sports networks and across the internet. They were forced to limit the number of orders available per game to meet demand, and chose 312 orders as the cap to celebrate Mariners great Edgar Martinez's lifetime batting average of 0.312. Isolated events like this bear proof to a broader movement towards acceptance and inclusion into the diets of (at least some) some of the public who traditionally would not have eaten insects in North America.

With the 2016 founding of the NACIA, the North American edible insects industry has their first trade association focusing on consumer education and research prioritization. More chefs are adding insects to their menus; more farmers are growing insects for food; more product makers are using insects in novel and unique ways and the public is increasingly more aware of the costs associated with their food choices more generally and the potential for insects as a nutritious food source more specifically. These authors anticipate the continued, if not accelerated, growth of the industry into more and more consumers' daily lives. As farming and processing systems are made more efficient, and insect ingredients' applicability is better understood and further explored, the price for insect products will continue to fall towards a more competitive cost comparison with traditional protein sources, making these twenty-first century livestock products not only desirable, but attainable for the average consumer.

References

Aldrich J (1921) Coloradia pandora Blake, a moth of which the caterpillar is used as food by mono Lake Indians. Ann Entomol Soc Am 14:36–38

Berenbaum MR (1996) Bugs in the system: insects and their impact on human affairs. Basic Books, New York

Brickell J (1737) The natural history of North Carolina. Johnson Publishing Company, Murfreesboro

Burgh RF, Scoggin CR (1948) Archaeology of Castle Park, Dinosaur National Monument. University of Colorado Press, Boulder

Carr LG (1951) Interesting animal foods, medicines, and omens of the eastern Indians, with comparisons to ancient European practices. J Wash Acad Sci 41(7):229–235

Christenson AJ (2007) Popol Vuh: sacred book of the Quiché Maya people. Mesoweb Publications, University of Oklahoma Press, Norman

Cohen JH (2004) The culture of migration in southern Mexico. University of Texas Press, Austin

Costa-Neto EM, Ramos-Elorduy J (2006) Los insectos comestibles de Brasil: etnicidad, diversidad e importancia en la alimentación. Boletin Sociedad Entomológica Aragonesa 38:423–442. Espeitx E

Ebeling W (1986) Handbook of Indian foods and fibers of arid America. University of California Press, Berkeley

Egan HR (1917) Pioneering the west, 1846 to 1878: Major Howard Egan's diary. Also thrilling experiences of pre-frontier life among Indians, their traits, civil and savage, and part of autobiography, inter-related to his Father's. Skelton Publishing Company, Salt Lake City

Felt E (1918) Caribou warble grubs edible. J Econ Entomol 11:482
Grieshop JI (2006) The envios of San Pablo Huixtepec, Oaxaca: food, home, and transnationalism. Hum Organ 65(4):400–406
Gustafson K (2016) Would you eat crickets? Some grocery stores are betting on it. Forbes https://www.forbes.com/forbes/welcome/?toURL=https://www.forbes.com/sites/katherinegustafson/2016/09/01/would-you-eat-crickets-some-grocery-stores-are-betting-on-it/&refURL=https://www.google.com/&referrer=https://www.google.com/
Hammer UT (1986) Saline lake ecosystems of the world, vol 59. DR W. Junk Publishers, Dordrecht
Hearne S, Tyrrell JB (1795) A journey from prince of Wales's fort in Hudson's bay to the Northern Ocean, vol 445. The Champlain Society, Toronto
Jongema Y (2017) Worldwide list of edible insects. https://www.wur.nl/upload_mm/8/a/6/0fdfc700-3929-4a74-8b69-f02fd35a1696_Worldwide%20list%20of%20edible%20insects%202017.pdf
Leonard WR (2003) Food for thought. Sci Am 13:62–71
Lesnik JJ (2017) Not just a fallback food: global patterns of insect consumption related to geography, not agriculture. Am J Hum Biol 00:e22976
Madsen DB, Schmitt DN (1998) Mass collecting and the diet breadth model: a Great Basin example. J Archaeol Sci 25(5):445–455
Morgan LH (1877) Ancient Society. World Publishing: New York.
Orr PC (1952) Preliminary excavations of Pershing County caves. Nevada State Museum, Department of Archeology, Carson City
Ramos-Elorduy J (2009) Anthropo-entomophagy: cultures, evolution and sustainability. Entomological Research 39(5):271–288
Ramos-Elorduy J, Pino J (1998) Insectos comestibles del estado de México y determinación de su valor nutritivo. Anales del Instituto de Biologia, UNAM 69:65–104
Ramos-Elorduy J, Pino Moreno JM (2004) Los Coleoptera comestibles de México. An Inst Bio 75(1):149–183
Ramos-Elorduy J, Viejo Montesinos JL (2007) Los insectos como alimento humano: Breve ensayo sobre la entomofagia, con especial referencia a México. Bol R Soc Esp Hist Nat Sec Biol 102(1–4):61–84
Ramos-Elorduy, Moreno JMP, Prado EE, Perez MA, Otero JL, de Guevara OL (1997) Nutritional value of edible insects from the state of Oaxaca, Mexico. J Food Compos Anal 10(2):142–157
Ramos-Elorduy J, Costa NEM, Ferreira dos Santos J, Pino MJM, Landero-Torres I, Ángeles CSC, García PA (2006) Estudio comparativo del valor nutri- tivo de varios coleoptera comestibles de México y Pachymerus nucleorum (fabri- cius, 1792) (bruchidae) de Brasil. Inter- ciencia 31(7):512–516
Ramos-Rostro B, Figueroa-Colin S, Olguin-Arredondo H (2009) Extraccion de hormigas mieleras (Myrmecystus Mexicanus): una reseña sobre el trabajo de campo, en Santo Domingo, Axapusco, Estado de Mexico. Culinaria revista virtual gastronomica (5):21–34
Russell F (1898) Explorations in the far north. University of Iowa, Iowa City
Sandel A (1715) Memorandum. Mitchell and Miller's Medical Repository 4:71
Schrader J, Oonincx DGB, Ferreira MP (2016) North American entomophagy. J Insects Food Feed 2(2):111–120
Shockley M, Allen RN, Gracer D (2017) Product development and promotion. In Insects as food and feed: from production to consumption. Wageningen Academic Publisher.
Steward JH (1943) Culture element distributions: XXIII. Berkeley, Northern and Gosiute Shoshoni, University of California Press
Sutton MQ (1988) Insects as food : aboriginal entomophagy in the Great Basin. Ballena Press, Menlo Park
Sutton MQ (1995) Archaeological aspects of insect use. J Archaeol Method Theory 2(3):253–298
Thrussell E (2016) A recipe for identity: food and culture in Oaxaca, Mexico. University of Adelaide, Adelaide
Troitino C (2016) Why Pepsi's CEO believes that bugs are the protein of the future. Forbes http://www.forbes.com/sites/christinatroitino/2016/10/31/why-pepsis-ceo-believes-that-bugs-are-the-protein-of-the-future/#419a01e52211

Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects: future prospects for food and feed security, vol 171. Food and Agriculture Organization of the United Nations (FAO). Rome

Wakefield EG, Dellinger SC (1936) Diet of the bluff dwellers of the Ozark Mountains and its skeletal effects. Ann Intern Med 9(10):1412–1418

Wilken GC (1970) The ecology of gathering in a Mexican farming region. Econ Bot 24(3):286–295

Yarnell RA (1974) Intestinal contents of the salts cave mummy and analysis of the initial salts cave flotation series. In: Watson PJ (ed) Archeology of the mammoth cave area. Academic Press, New York, pp 109–112

Part III
Nutrition and Health

Insects and Human Nutrition

Nanna Roos

Abstract Despite high diversity in species as well as metamorphological life-stages, edible insects are essentially an animal-source food contributing high quality protein and fat when viewed in the context of human nutrition. The nutritional contribution of insects to diets in populations where insects are consumed as a part of traditional diets is largely unknown because of lack of data and information on insect supply and consumption. Protein and fat nutritional quality varies between insects and the life-stage of consumption (egg, larvae, pupae, adult) when they are consumed, and the feeding history of the insects. Many insects have high contents of minerals important for human nutrition, such as iron and zinc, though the bioavailability in humans needs to be documented for a complete evaluation of the nutritional contribution. Few data are available on vitamin contents in insect. Insects have a high potential to improve the nutritional quality of diets in populations at risk of malnutrition, either consumed whole as in traditional diets, or as ingredients in processed foods.

1 The Nutritional Composition of Insects

With more than 2000 recorded insect species being edible, the diversity of the nutritional composition is equally high. In addition, insects are consumed at various metamorphological life-stages. Some species are preferred to be consumed as egg, such as the weaver ant (*Oecophylla sp*), while other insects preferred eaten at the larvae stage, such as mealworms (*Tenebrio molitor*, *Alphitobius diaperinus*) or mopane worm (*Imbrasia belina*). The Orthoptera order of insects includes several suborders highly favoured for consumption, such as grasshoppers (*Caliphera*), locust (*Acrididae*) and crickets (*Gryllidae*). The Orthoptera species are characterized by incomplete metamorphosis which means these insects do not have a larval/pupal stage between the hatching of the egg and the adult grasshopper or cricket.

N. Roos (✉)
Department of Nutrition, Exercise and Sports (NEXS), University of Copenhagen, Copenhagen, Denmark
e-mail: nro@nexs.ku.dk

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_5

Despite this high diversity in species as well as metamorphosis, edible insects viewed in the context of human nutrition are essentially an animal-source food with the primary composition of protein and fat. In addition to a body structure of muscles and deposits of fat and other tissues, insects are characterized by having an exoskeleton which is made up of chitin. Chitin is a complex polysaccharide structure which in the context of human nutrition essentially is recognized as dietary fiber, assumed to pass largely undigested through the gastrointestinal tract (Rumpold and Schluter 2013). Some digestion may, however, occur, indicated by the finding of chitin-degrading enzymes – chitinases – in the human digestive fluid in certain human populations (Paoletti et al. 2007). While protein, fat and chitin make up the major body structures of the insect, and hereby also the main contribution when insects are consumed in a diet, the fully functional biological organism of an insect also requires a complexity of minerals and vitamins to support the metabolic functions. Insects, in any metabolic stage, are therefore also a source of various micronutrients of value for human nutrition. The contents as well as the bioavailability of micronutrients from insects is highly variable between species and metamorphological life-stages (Rumpold and Schluter 2013), as well as being impacted by the metabolic stage (starved, well fed) of the insect.

2 The Nutritional Role of Edible Insects in Traditional Diets

The highest diversity of edible insect species consumed in traditional diets is found in Asia, followed by Africa and South America (Costa-Neto 2015; Kelemu et al. 2015; Yen 2015). These are also regions where proportions of the populations are living in poverty leading to risk of malnutrition, especially countries and regions in Asia and Africa, with either child under nutrition, micronutrient deficiencies, adult obesity being highly prevent, alone or in combinations (IFPRI 2016). However, the nutritional contributions of insects to diets in these populations are largely unknown because of a fundamental lack of data and information on insect supply and consumption. Edible insects are generally not recorded in national and international food supply and trade statistics, and therefore also not included in the global food statistics compiled by UN Food and Agriculture Organization (FAO). Despite that the global food supply statistics provide information on food availability only on national levels, and then do not tell how food sources are consumed in specific population groups, it is still a valuable tool to understand the local and global food systems. The lack of records of edible insects is a reflection of insects belonging to the informal food sector, and hence also not covered by national legislation and regulations (Belluco et al. 2017).

Even in countries with traditional use of insects, insects are typically not covered in national food consumption surveys, leaving an information gap on the actual contribution to nutritional intakes. Information on insect consumption on population level is very scarce. Probably the only nationally representative survey in insect consumption was conducted in Laos PDR (Barennes et al. 2015). Laos PDR has a long history of insect consumption. The survey conducted among 30 ethnic groups showed that nearly all (98%) of the representatively selected respondents (n = 1059 plus 256 insect vendors) consumed insects, but the majority did it infrequently following seasonal availability of insects. However, 13% reported that they consumed insects daily or weekly, and the vast majority would eat more insects if they were accessible year-round. The dominant insect species consumed were weaver ant eggs, various cricket species, cicada, bamboo worm and wasps. The study in Laos PDR did not directly quantify the amounts of insects consumed and hence not the nutritional contribution to the diet. But the survey demonstrated that insects play a role in the diet of most people in Laos PDR, and have a potential to contribute much more to improve the diet in Laos PDR if insects were more available.

A range of studies on specific edible insect species in various cultures show that the perception and significance of insects in traditional diets is equally variable. Insects are highly preferred and valued food in many of the insect eating cultures, for example documented by in *On Eating Insects: Essays, Stories and Recipes* (Evans et al. 2017), while other cultures may have consumed insects in periods of food shortage. To which extend insects have been consumed only as 'hunger food' in situations of food scarcity is difficult to document. Reporting from predominately western researchers and observes of insect consumption – often articulated as 'entomophagy' – have historically tended to be viewed as a 'hunger food' consumed only in scarcity of other foods (Evans et al. 2015), while the true role of insects in traditional diets and food systems are much more complex.

3 What Do We Know About Nutritional Composition of Insects

Numerous studies on the nutritional composition of various insects species have been published over the decades, and the potential of insects as a highly nutritious food have over the years caught the attention from scientists from food science (YhoungAree et al. 1997), nutrition (Christensen et al. 2006), entomology (Gahukar 2011; Yen 2009) and even from space science (Tong et al. 2011). Several review papers have compiled published food compositions of insects across species to document variation, for example Rumpold and Schluter (2013). While edible insects have been largely ignored in national food composition tables and databases, the recent increased recognition of edible insects in food systems have supported that insects are better represented when food composition tables are updated, and hereby facilitate that the nutritional contribution from insects can be included when food consumption is assessed in various populations. Without the systematic access to nutritional composition of insects, as made available in food composition databases, the inclusion of insects in food consumption surveys is difficult. Since 2000, the food composition table compiled for the Southeast Asian region (Puwastien et al. 2014) has included a section on 'miscellaneous food' listing nutrient composition of

10 edible insects: bamboo caterpillar, buffalo dung beetle, cricket, mole cricket, giant water bug, June beetle, locust, red ant (differentiated on whole, larvae and young female), silk worm pupae and true water beetle. The regional local names (thai, khmer and other languages) are included, but the scientific names of the insects are not listed, so the list is likely to cover species which share common names. The first food composition table for Nigeria was released in 2017, and included nutritional information on three insect species: African Palm weevil (*Rhynchophorus phoenicis*), *Orycteo rhinoceros* and winged termites (*Macrotermes bellicosus*) (NFDN 2017). However, Nigeria has a rich tradition for traditional insect consumption, with more than 50 species recorded as edible in the southern part of the country (Kelemu et al. 2015), so much more insect species need to be included in the food composition table in the future to fully evaluate the nutritional contribution from insects to the Nigerian diets.

The nutritional information of various foods, including insects, needs to meet standards of quality to be included in food composition data. The nutritional values should be representative for biological, seasonal and other variations of the food item by averaging analyzed contents of multiple independently collected samples. Also, the analytical methods applied for the various nutrients should be validated and under quality control. The INFOODS program under the UN Food and Agricultural Organization (FAO) in Rome has in decades coordinated and published food composition data and tables. In 2010 INFOODS published the Food Composition Database for Biodiversity, with the aim of making nutritional values of wild and underutilized foods available (Charrondière et al. 2013). In the version 4.0 of this database, a total of 471 entries of insects covering insect species and various preparations were included (FAO-INFOODS 2017). Insects are included as a sub-category of 'meat and poultry'. The nutritional information is compiled from published studies. However, in the preparation of this first international food composition table including insects, it was also found that studies on the nutritional composition of insects were of very variable quality, and future studies needs to comply with general standards for food composition data in order to contribute to improve our access to document the nutritional contribution from insects to human nutrition (Nowak et al. 2016). On the course of including edible insects in the more formalized food systems and for the evaluation of the nutritional contribution in various populations, it is needed to secure that the nutritional composition is documented meeting the standards for inclusion in food composition tables.

4 The Nutritional Quality of Insects

Generally, the macronutrients composition of insects is as characteristic for meat and fish, with typical range across insect species of 40–70% protein of dry weight, and complementary variable fat contents. Fat content is typically in the range of 5–40% of the dry matter, but has been reported in the extreme high as 70% in samples of palm weevil larvae (*Rhynchophorus phoenicis*) (Rumpold and Schluter 2013), or

Table 1 Approximate macronutrient composition (protein and fat) compiled across various sources for typical farmed insect species

Common name in English	Insect order and species	Life-stages used	Protein (% of dry matter)	Fat (% of dry matter)
Crickets	Order: Orthoptera			
House cricket	*Acheta domesticus*	Adults	60–75	7–20
Banded cricket	*Gryllodes sigillatus*	Adults	60–75	7–20
Grasshoppers/locusts	Order: Orthoptera			
Migratory locust	*Locusta migratoria*	Adults	40–60	10–25
American grasshopper	*Schistocerca americana*	Adults	40–60	10–25
Flies	Order: Diptera			
Common housefly	*Musca domestica*	Larvae	55–70	10–25
Black soldier fly	*Hermetia illucens*	Larvae/prepupae	40–60	20–40
Beetles	Order: Coleoptera			
Mealworm	*Tenebrio molitor*	Larvae	45–55	25–35
Giant mealworm	*Zophobas atratus/morio*	Larvae	40–50	40–45
Lesser mealworm	*Alphitobius diaperinus*	Larvae	45–60	25–30
Moths	Order: Lepidoptera			
Greater wax moth	*Galleria mellonella*	Larvae	35–45	40–60
Lesser wax moth	*Achroia grisella*	Larvae	35–45	40–60
Silkworm	*Bombyx mori*	Larvae/pupae	50–70	8–10

21 g/100 g fresh weight (Fogang et al. 2017). Typical moisture content for insects is around 65%. The macronutrient composition within insect species also varies considerable between batches and studies, for example shown for mealworms (Nowak et al. 2016). In Table 1, approximate ranges of fat protein and fat for the common insect species currently being farmed are shown.

4.1 Protein Quality

Protein quality in relation to human requirements can be evaluated based on amino acid composition and the digestibility of the protein, assessed in various standardized methods. The amino acid profiling of various insect species are available from published sources. The overall picture is amino acid profiles favourable for human requirements, including essential amino acids. However, in order to provide a complete picture of the protein quality, the digestibility of the proteins needs to be known. Few insect species have been fully evaluated for digestibility and quality in relation to human requirements. One assessment of protein quality of silk worm larvae applying the protein digestibility-corrected amino acid score (PDCAAS)

(Schaafsma 2000) showed that the protein quality was high scoring similar to meat, and that the limiting amino acid for complying with human requirements was leucine (Longvah et al. 2011). Along with earlier studies using less specialized assessment methods for protein quality (Ramos-Elorduy et al. 1997; Verkerk et al. 2007), the PDCAAS study strongly supports that insects are nutritionally a highly valuable protein source which can improve diets by supplying essential and digestible amino acids, especially in an otherwise plant-dominated diet, typical in developing countries. However, due to the highly diverse biology of edible insects, the protein quality needs to be assessed in more species.

Since 2011 protein quality has been recommended to be assessed by the Digestible Indispensable Amino Acid Score (DIAAS) method (Lee et al. 2016) to get a more correct and directly comparable measure for protein quality between different food sources. The DIAAS method is based on advanced assessment in a piglet animal model. To date, no DIAAS assessments of insect protein have been published.

4.2 Fat Quality

The nutritional quality of fat in food is determined by the fatty acid composition. The compositions of saturated fat (SFA), monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) determines the nutritional quality of dietary fat. Replacing SFA with PUFA in diets are documented to reduce risk of coronary heart disease (FAO 2010) and intake of long-chained omega-3 PUFA are beneficial for the brain development of infants and young children (Lauritzen et al. 2001). The fat quality of edible insects is highly variable between species (Rumpold and Schluter 2013) and is also affected by what the insects have been feeding on (Barroso et al. 2017). Overall, insects can be valuable sources of the essential omega-3 and omega-6 fatty acids (Michaelsen et al. 2011; Rumpold and Schluter 2013). However, from the current knowledge they are unlikely to be significant sources of the special long-chained PUFAs, docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), specifically known from marine food sources (Michaelsen et al. 2011).

We as humans need to get the essential omega-3 (α-linolenic acid) and omega-6 (linoleic acid) fatty acids from the diet. While omega-6 fatty acids are available from various food sources, also plant foods, omega-3 fatty acids are scarcer, and at risk of being deficient in diets with little animal-source foods. One way to characterize the fatty acid quality is the ration between omega-6 and omega-3 fatty acids. A lower ration indicates a good source of omega-3. This ratio was found to be 3:1 in field cricket (*Teleogryllus testaceus*) and also in Cambodian spider (*Haplopelma albostriatum*), which is nutritional beneficial compared to most meat sources, and comparable to many freshwater fish – though not on the level as in marine fish (Michaelsen et al. 2011).

4.3 Vitamins and Minerals

Insects are generally eaten whole, including all tissue types such as head, organs etc. in the edible portion. This contribute to a generally higher content of minerals and vitamins, comparing to animal-source foods such as meat where a large proportion of the animal is not considered edible. This beneficial aspect of insects being consumed whole is similar to that the consumption of small fish, which are consumed whole with bones, head etc., is a much better source of minerals and vitamins compared to larger fish where only the fillet is consumed (Roos et al. 2007). Reported contents of minerals in edible insects across species and orders are highly variable, but generally, insects are good sources of minerals like iron and zinc (Finke 2015; Kinyuru et al. 2013; Rumpold and Schluter 2013), which are also minerals which are often deficient in diets in low- and middle income countries (IFPRI 2016). Iron and zinc from animal-food sources are beneficial because of high bioavailability. However, the specific bioavailability of minerals from insects has not been assessed and needs to be documented to fully evaluate the nutritional contribution.

There are little data on vitamins in edible insects. The INFOODS food composition table has few entries or vitamin contents in insects. There are, for example, only 14 entries for vitamin A contents in insects, all from termites and grasshoppers in Kenya (FAO-INFOODS 2017). The values are in the range of 80–150 ug retinol/100 g edible portion, which is a considerable source vitamin A source, especially in Kenya where the population is at risk of vitamin A deficiency.

4.4 Insects as Ingredient in Processed Foods

Insects are show great promise as ingredients in processed foods, to enhance the nutritional quality. A study in Kenya showed that adding 10% powdered cricket to a biscuit enhanced the nutritional quality similar to adding milk powder, and the biscuit would be suited for improving school feeding programs (Homann et al. 2017). Extraction of functional ingredients from insects is also viewed as highly promising (Hall et al. 2017), and the nutritional contributions from such extracts should be assessed, additional to the functionality.

5 Conclusion

Insects are nutritionally an animal-source food, contributing high quality protein and micronutrients to a varied diet. Insects are also a source of fat which has variable quality depending on the species and feeding history of the insects.

References

Barennes H, Phimmasane M, Rajaonarivo C (2015) Insect consumption to address undernutrition, a national survey on the prevalence of insect consumption among adults and vendors in Laos. PLoS One 10:e0136458

Barroso FG, Sanchez-Muros MJ, Segura M, Morote E, Torres A, Ramos R, Guil JL (2017) Insects as food: enrichment of larvae of Hermetia illucens with omega 3 fatty acids by means of dietary modifications. J Food Compos Anal 62:8–13

Belluco S, Halloran A, Ricci A (2017) New protein sources and food legislation: the case of edible insects and EU law. Food Sec 9:803–814

Charrondière RU, Stadlmayr B, Rittenschober D, Mouille B, Nilsson E, Medhammar E, Olango T, Eisenwagen S, Persijn D, Ebanks K, Nowak V, Du J, Burlingame B (2013) FAO/INFOODS food composition database for biodiversity. Food Chem 140:408–412

Christensen DL, Orech FO, Mungai MN, Larsen T, Friis H, Aagaard-Hansen J (2006) Entomophagy among the Luo of Kenya: a potential mineral source? Int J Food Sci Nutr 57:198–203

Costa-Neto EM (2015) Anthropo-entomophagy in Latin America: an overview of the importance of edible insects to local communities. J Insects Food Feed 1:17–23

Evans J, Alemu MH, Flore R, Frøst MB, Halloran A, Jensen AB, Maciel-Vergara G, Meyer-Rochow VB, Münke-Svendsen C, Olsen SB, Payne C, Roos N, Rozin P, Tan HSG, van Huis A, Vantomme P, Eilenberg J (2015) Entomophagy: an evolving terminology in need of review. J Insects Food Feed 1:293–305

Evans J, Flore R, Froest MB (2017) On eating insects: essays, stories and recipes. Phaidon Press, London, New York

FAO (2010) Fats and fatty acids in human nutrition. FAO nutrition report 91. FAO, Rome

FAO-INFOODS (2017) Food composition database for biodiversity version 4.0. FAO, Rome

Finke MD (2015) Complete nutrient content of three species of wild caught insects, pallid-winged grasshopper, rhinoceros beetles and white-lined sphinx moth. J Insects Food Feed 1:281–292

Fogang AR, Kansci G, Viau M, Hafnaoui N, Meynier A, Demmano G, Genot C (2017) Lipid and amino acid profiles support the potential of Rhynchophorus phoenicis larvae for human nutrition. J Food Compos Anal 60:64–73

Gahukar R (2011) Entomophagy and human food security. Int J Trop Insect Sci 31:129–144

Hall FG, Jones OG, O'Haire ME, Liceaga AM (2017) Functional properties of tropical banded cricket (Gryllodes sigillatus) protein hydrolysates. Food Chem 224:414–422

Homann AM, Ayieko MA, Konyole SO, Roos N (2017) Acceptability of biscuits containing 10% cricket (Acheta domesticus) compared to milk biscuits among 5-10-year-old Kenyan schoolchildren. J Insects Food Feed 3:95–103

IFPRI (2016) Global nutrition report 2016: from promise to impact: ending malnutrition. International Food Policy Research Institute (IFPRI), Washington DC

Kelemu S, Niassy S, Torto B, Fiaboe K, Affognon H, Tonnang H, Maniania NK, Ekesi S (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insects Food Feed 1:103–119

Kinyuru JN, Konyole SO, Roos N, Onyango CA, Owino VO, Owuor BO, Estambale BB, Friis H, Aagaard-Hansen J, Kenji GM (2013) Nutrient composition of four species of winged termites consumed in western Kenya. J Food Compos Anal 30:120–124

Lauritzen L, Hansen HS, Jørgensen MH, Michaelsen KF (2001) The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina. Prog Lipid Res 40:1–94

Lee WT, Weisell R, Albert J, Tome D, Kurpad AV, Uauy R (2016) Research approaches and methods for evaluating the protein quality of human foods proposed by an FAO expert working group in 2014. J Nutr 146:929–932

Longvah T, Mangthya K, Ramulu P (2011) Nutrient composition and protein quality evaluation of eri silkworm (Samia ricinii) prepupae and pupae. Food Chem 128:400–403

Michaelsen KF, Dewey KG, Perez-Exposito AB, Nurhasan M, Lauritzen L, Roos N (2011) Food sources and intake of n-6 and n-3 fatty acids in low-income countries with emphasis on infants, young children (6–24 months), and pregnant and lactating women. Matern Child Nutr 7:124–140

NFDN (2017) Nigerian food database. Nigeria Foods Database Network (NFDN). Available: http://nigeriafooddata.ui.edu.ng/

Nowak V, Persijn D, Rittenschober D, Charrondiere UR (2016) Review of food composition data for edible insects. Food Chem 193:39–46

Paoletti MG, Norberto L, Damini R, Musumeci S (2007) Human gastric juice contains chitinase that can degrade chitin. Ann Nutr Metab 51:244–251

Puwastien P, Burlingame B, Raroengwichit M, Sungpuag P (2014) ASEAN food composition tables ASEANFOODS coordinator and INFOODS Regional Database Centre. Thailand, Institute of Nutrition, Mahidol University (INMU)

Ramos-Elorduy J, Moreno JMP, Prado EE, Perez MA, Otero JL, Larron De Guevara O (1997) Nutritional value of edible insects from the State of Oaxaca, Mexico. J Food Compos Anal 10:142–157

Roos N, Wahab M, Chamnan C, Thilsted SH (2007) The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. J Nutr 137:1106–1109

Rumpold BA, Schluter OK (2013) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57:802–823

Schaafsma G (2000) The protein digestibility-corrected amino acid score. J Nutr 130:1865S–1867S

Tong L, Yu X, Liu H (2011) Insect food for astronauts: gas exchange in silkworms fed on mulberry and lettuce and the nutritional value of these insects for human consumption during deep space flights. Bull Entomol Res 101:613–622

Verkerk MC, Tramper J, van Trijp JCM, Martens DE (2007) Insect cells for human food. Biotechnol Adv 25:198–202

Yen AL (2009) Edible insects: traditional knowledge or western phobia? Entomol Res 39:289–298

Yen AL (2015) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insects Food Feed 1:33–55

YhoungAree J, Puwastien P, Attig GA (1997) Edible insects in Thailand: an unconventional protein source? Ecol Food Nutr 36:133–149

The Role of Edible Insects in Diets and Nutrition in East Africa

John N. Kinyuru, Dorothy Nyangena, Edwin Kamau, Alex Ndiritu, Joyce Muniu, Carolyne Kipkoech, Johnson Weru, Nancy Ndung'u, and Mercy Mmari

Abstract Insects have been used as food, medicine and in rituals by a number of communities in the East African region comprising of Kenya, Uganda and Tanzania over centuries. Progressively, farmed edible insects mainly crickets and grasshoppers are gaining popularity within the region. However the utilization of the edible insects is hampered by lack of storage and preservation facilities in the rural areas leading to high postharvest losses. Sun drying and roasting have been the main processing methods applied for decades by communities consuming edible insects such as the Luo from Kenya. Recently there has been incorporation of insects as an ingredient in processing of baked products and complementary foods. Culture, taboos, customs and ethnic preferences have highly influenced the consumption of edible insects in East Africa. Edible insects such as grasshoppers, mayfly and termites that are consumed in this region have been shown to be source of both macro and micro nutrients and other components such as chitin which has been linked to improved health and better management of chronic diseases. Therefore edible insects promises to be a part of the solution to food and nutrition security within the East African region.

1 Introduction

This chapter will cover edible insects consumed in the East African region and will explore the diversity, nutritional profiles, harvesting and processing and their contribution to food and nutrition security. In Africa, various studies have recorded different number of edible insects, with numbers varying from 246 species from 27 countries (van Huis 2003). A survey conducted by International Centre of Insects Physiology and Ecology (ICIPE), revealed 470 species of edible insects existed in Africa (Kelemu et al. 2015).

J. N. Kinyuru (✉) · D. Nyangena · E. Kamau · A. Ndiritu · J. Muniu · C. Kipkoech · J. Weru
N. Ndung'u · M. Mmari
Department of Food Science and Technology,
Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
e-mail: jkinyuru@agr.jkuat.ac.ke

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_6

In East Africa insects have been utilized over centuries as food, feed, medicine and in witchcraft. However due to change in eating habits, preferences and food and nutrition insecurity a wider consumption of edible insects have been reported in this region (Ayieko and Oriaro 2008). The key insect orders consumed in East Africa include *Lepidoptera, Coleoptera, Hymenoptera, Orthoptera, Hemiptera, Isoptera* and *Diptera* at different stage of their lifecycle. In Zambia Mopani worm (*Imbrasia belina*) is consumed and sold in the streets of Lusaka usually in dried or roasted form (Ghaly 2009). Tree locust (*Anacridium melanorhodon melanorhodon*) can easily be found in Khartoum, Sudan sold as either flour or fried (Babiker et al. 2007). The Luo community who reside along the Lake Victoria in Kenya have used the mayfly for cultural practices and also as a source of income (Ayieko and Oriaro 2008). Additionally termites (*Macrotermes subhyalinus*) and Longhorn grasshopper (*Ruspolia differens*) are a delicacy in this region of Kenya (Kinyuru et al. 2009, 2010a, b). In Uganda edible Grasshopper (*Ruspolia nitidula*) commonly known as Senene is highly consumed (Ssepuuya et al. 2016).

Furthermore in some of the Eastern African countries, edible insects are roasted and sun dried (Ghaly 2009). In Uganda grasshoppers are fried prior to selling in the market (Agea et al. 2008). Termites are toasted in their own oil for about 5 min and thereafter consumed alone or as a part of a meal by communities in the western region of Kenya (Kinyuru et al. 2010a, b). In Sudan the tree locust are boiled before being sold in the markets of Khartoum (Babiker et al. 2007). Most of these processing procedures are done by women and children. For instance the drying, roasting, packaging, mixing and selling of the mopane caterpillar (*Imbrasia belina*) in Zimbabwe is done by women (Kozanayi and Frost 2002).

A key technical challenge that hampers the utilization of edible insects in East Africa is lack of proper processing, storage and preservation enablers. For instance there is lack of electricity especially in the rural areas where the harvesting of edible insects is done, additionally the high temperature in the tropics causes faster spoilage and as a result there is high postharvest loss (Ayieko 2010). However, sun drying offers a cheap alternative to dry and preserve the harvested insects (Ayieko et al. 2011; van Huis 2015).

2 Harvesting, Handling and Processing of Edible Insects in East Africa

2.1 Harvesting

In the past, most wild-harvested insects were consumed at the household level, and the quantities collected were determined by day to day consumption requirements. Today, insects have become an additional source of income and the portion harvested has increased gradually (FAO 2013; Yen 2015). Edible insects thrive in a variety of habitats such as vegetation, roots, branches and trunks of trees or soils (FAO 2013).

Fig. 1 Day time view of a grasshopper trap ready for harvesting

Most of the insects consumed are often collected by women and children from the wild (van Huis 2015) depending on their seasonality (Ayieko and Oriaro 2008).

Light traps are the most commonly used methods to catch edible insects in Western Kenya (Ayieko and Oriaro 2008; Ayieko et al. 2011). This is particularly so for insects which have a preference to swarm at night such as some species of termites and grasshoppers. In Tanzania for example, traditional traps are made of iron sheets and bright light, so as to attract grasshoppers in the night (Figs. 1 and 2). Caterpillars are harvested from forest trees that form new leaves at the beginning of the rainy season (van Huis 2003).

Insects that inhabit soils such as beetles, are often picked by hand. A researcher observed that during the onset of rains winged termites emerge from tunnels and are collected, additionally the termites are also harvested by placing a bowl of water under a source of light since termites are attracted to light (Kinyuru et al. 2009). Additionally mayflies are collected by villagers along the lake (Ayieko and Oriaro 2008). With the advent of farming of insects such as crickets and grasshoppers, conventional methods of harvesting are now being applied, hence easing the pressure applied on wild edible insect species.

Fig. 2 Night view of a grasshopper light trap during harvesting

2.2 Traditional Processing for Human Consumption

Communities in the East African region consume the insects raw or process them to meet their tastes and preferences. Some of these insects need; removal of appendages, de-winging, degutting, beheading, washing with water to remove any dirt, (Aguilar-Miranda et al. 2002; FAO 2010; Kinyuru et al. 2010a, b) before they are further processed (Fig. 3 and Table 1).

2.3 Industrial Processing

Recently, a lot of interest has been directed to evaluating the production and processing of edible insects and push for its recognition as a food ingredient in food processing. This is especially after studies have shown the safety of edible insects (Konyole et al. 2012). A study concluded that termites and mayfly have a great potential of being utilized as supplements in processing of crackers/biscuits (Ayieko 2010). Similarly incorporation of termite meal in bun production is not only an adoptable

Fig. 3 Women removing appendages and de-winging grasshoppers after harvesting in a market in Tanzania

Table 1 Processing methods of different edible insect species consumed in East African countries

Species	Common name	Stage consumed	Processing method	Country consumed
Acheta domesticus[1]	House cricket	Adult	Toasted and/or dried	Kenya, Uganda
Anaphe panda[2]	Silk worm	Larvae	Fried or roasted	Tanzania
Carebara vidua[3]	Black ants	Adult	Washed and fried, de-headed	Kenya
Chaoborus edulis[4]	Glass worm	Adult	Ground and sun dried	Uganda
Macrotermes spp[5,6]	Termites; white ants	Winged adult (Alates)	De-winged, toasted and/ or dried, salting, boiling	Uganda, Kenya
Ruspolia differens[6]	Long-horned grasshopper	Adult	De-winged, toasted and/ or dried, salting	Kenya, Uganda, Tanzania
Ruspolia nitidula[5,7,8]	Long-horned grasshopper	Adult	De-winged, toasted and/ or dried, salting, boiling	Kenya, Uganda, Tanzania

[1]Ayieko (2010), [2]Defoliart (1995), [3]Ayieko and Kinyuru (2012), [4]van Huis (2003), [5]Agea et al. (2008), [6] Kinyuru et al. (2010a, b), [7] Mbabazi (2011), [8] Ssepuuya et al. (2016)

process but also a way of providing nutrients (Kinyuru et al. 2009). Additionally it has been demonstrated that termites can be used in processing of complementary food with considerably good shelf life (Kinyuru et al. 2015).

Wheat based products have been developed with incorporation of edible insects. For example buns with 5% of wheat replaced with termite meal (Kinyuru et al. 2009) have been developed. Termite and mafly meal have also been used at varying percentages to supplement wheat meal in the production of crackers and muffins that had high nutrient content and consumer acceptance (Ayieko et al. 2010).

A study under the WinFood project funded by DANIDA with the goal of improving nutritional status of infants and young children by utilizing traditional foods in Kenya, involved processing of winged termites, *Macrotermes subhylanus,* into ready to cook extruded complimentary flour (Kinyuru et al. 2015). Industrial processing in East Africa is therefore a possibility, but, it is hampered by lack of adequate amounts from wild harvesting hence necessitating commercial farming of insects. To acquire large quantities of quality insects, automation of both farming and processing methods is vital, which remains a challenge for the development of the sector.

2.4 Storage and Preservation

Edible insects, like any meat and meat products, are highly perishable and prone to microbial and chemical changes upon storage, due to their rich nutrient profile. Microbial contamination mainly occurs during handling, processing and storage (Braide et al. 2011a, b). Bacteria, yeasts and moulds such as *Staphylococcus aureus, Bacillus cereus, Escherichia coli, Enterobacteriaceae, bacterial spores, Proteus mirabilis, Aspergillus, Mucor, Penicillium* and *Fusarium* have been reported to be the major cause of spoilage in edible insects (Braide et al. 2011a, b: Klunder et al. 2012; Opara et al. 2012; Mujuru et al. 2014).. Microorganisms have also been reported to cause quality deterioration of the edible caterpillar of the emperor moth commonly known as *Mophane* (Gashe et al. 1997). Heat based processes have however been found to be effective in eliminating most microbes. Boiled crickets were noted to spoil rapidly while boiled, and dried crickets and grasshoppers were microbiologically stable during storage (Klunder et al. 2012; Ssepuuya et al. 2016).

Insect fats are highly susceptible to both oxidative and hydrolytic rancidity. Ready to eat and vacuum packed longhorn grasshopper (*Ruspolia nitidula)* that were stored at room temperature for 12 weeks, showed a gradual increase in acid value which stabilised at 3.2 mg KOH/g. This was higher than the recommended 2 mg KOH/g acid value of edible oils (Ssepuuya et al. 2016). Processes like freezing and refrigeration have been shown to encourage nutrient retention (Severi et al. 1997) and improve oil absorption and protein solubility hence increasing industrial applications of the insects (Nabayo et al. 2012).

2.5 Cultural Preferences Influencing Consumption of Insects

2.5.1 Appreciation for Edible Insects

Women of Baganda Kingdom in Uganda are prohibited to eat the edible grasshopper though allowed to catch and cook for their husbands. The husbands in return reward their women by giving them traditional dresses called *gomasi*. The more the grasshoppers a woman collects, the better the *gomasi* she gets from her husband. The male kings would exchange edible grasshoppers in a manner that enhanced social ties (Agea et al. 2008).

Among the Kikuyu tribe in Central Kenya, consumption of edible insects is not commonly accepted since they consider the practise uncivilised. Crickets were however considered an important source of food to the guerrilla fighters during the struggle for freedom in the 1950's as they were freely available in forests of Central Kenya. In Tanzania, the purple grasshopper is considered to be a delicacy for the royalties. It is hence more expensive in the market. Amidst all these cultural barriers, consumption of edible insects has been promoted based on four main points of reference namely high nutritional value, important environmental benefits, economic factors and gastronomic aspects (Ramos-Elorduy 2005).

2.5.2 Barriers to Consumption of Edible Insects

Preference and decision to consume edible insects are dependent on taboos, customs as well as ethnic preferences (van Huis 2003). Such peculiarity of edible insects from normal red and white meat as the absence of blood and such behaviours as swarming has been associated with such taboos (Fasoranti and Ajiboye 1993; van Huis 2003). For example pregnant women in Haya tribe of Tanzania are not allowed to eat the longhorn grasshoppers as they will give birth to children with a cone-shaped head (similar to grasshoppers' head). Giving the longhorn grasshopper to children is also associated with inability to speak well when they grow up (Musisi 1991).

3 Nutrient Profile of Edible Insects

Protein and fat are the major macronutrients in the reviewed edible insects while available carbohydrate is the least (Table 2). *Schistocerca gregaria* had the highest amounts of protein and *Ruspolia differens* the highest amounts of fat (Table 2). The protein content was within 35.34–61.32% reported by (Rumpold and Schluter 2013) for orders Isoptera and Orthoptera. The protein content of the reviewed edible insects compares to that of conventional livestock (Kinyuru et al. 2010a, b; Nadeau et al. 2014). *Ruspolia nitidula* recorded the highest amount of dietary fibre while *Macrotermes subylanus* the least (Kinyuru et al. 2013; Ssepuuya et al. 2016). A high

Table 2 Macronutrient composition of some edible insects in East Africa (On a dry matter basis)

Edible insects	Protein (%)	Fat (%)	Dietary Fiber (%)	Av. Carbohydrate (%)	Ash (%)
Ruspolia differens (green) fresh [1]	43.1	48.2	4.0	2.0	2.8
Ruspolia differens (green) toasted [1]		20			
Ruspolia differens (green) fresh dried [1]		43.1			
Ruspolia differens (brown) fresh [1]	44.3	46.2	5.0	2.0	2.6
Ruspolia differens (brown) toasted [1]		14.6			
Ruspolia differens (brown) fresh dried [1]		41.2			
Ruspolia nitidula (green) fresh [2]	40.3	42.4	14.3	3.2	4.0
Ruspolia nitidula (brown) fresh [2]	40.4	43.0	13.9	3.1	3.8
Macrotermes subylanus fresh dried [1]		42.3			
Macrotermes bellicosus (dewinged)[3]	39.7	4.0	6.21	2.4	4.7
Macrotermes subylanus (dewinged) [3]	39.3	44.8	6.4	1.9	7.6
Macrotermes subylanus (toasted) [1]		21.4			
Pseudacanthotermes militaris (dewinged) [3]	33.5	46.6	6.6	8.7	4.6
Pseudacanthotermes spiniger (dewinged) [3]	37.5	47.3	7.2	0.7	7.2
Carebara vidua [4]	40.8	47.5			1.6

[1]Kinyuru et al. (2010a, b), [2]Ssepuuya et al. (2016), [3]Kinyuru et al. (2013), [4]Ayieko and Kinyuru (2012)

percentage of the fibre is usually composed of chitin. *Pseudacanthotermes militaris* recorded the highest amount of available carbohydrates while *Pseudacanthotermes spiniger* the least (Kinyuru et al. 2013).

In addition to the macronutrient composition the edible insects vary in mineral and vitamin composition (Tables 3 and 4). The variation in nutritional profiles is attributed to differences in species, metamorphic stages, habitats and diets (van Huis 2003; Ayieko and Oriaro 2008; Ayieko 2010; Kinyuru et al. 2013). Some insects have been shown to have protein with good solubility and biological value (Omotoso 2006; Solomon et al. 2008), with amino acid profile that meets the human requirement (Table 5). The amino acid profile of proteins is a major determinant of protein quality. Leucine was the dominant amino acid in cricket and termites. This demonstrates the good quality of edible insects' proteins. In addition, to amino acid

Table 3 Mineral composition of some edible insects in East Africa

Edible insects	Calcium (mg/100 g)	Magnesium (mg/100 g)	Potassium (mg/100 g)	Sodium (mg/100 g)	Phosphorus (mg/100 g)	Iron (mg/100 g)	Zinc (mg/100 g)	Manganese (mg/100 g)	Copper (mg/100 g)
Ruspolia differens (green) fresh [1]	27.4	33.9	370.6	358.7	140.9	16.6	17.5	5.3	0.6
Ruspolia differens (Brown) fresh[1]	24.5	33.1	259.7	229.7	121.0	13.0	12.4	2.5	0.5
Ruspolia nitidula (green) fresh [2]			0.5		0.5				
Ruspolia nitidula (Brown) fresh [2]			0.6	0.5					
Macrotermes bellicosus (dewinged) [3]	63.6					116.0	10.8		
Macrotermes subhyalinus (dewinged) [3]	58.7					53.3	8.1		
Pseudacanthotermes militaris (dewinged) [3]	48.3					60.3	12.9		
Pseudacanthotermes spiniger (dewinged) [3]	42.9					64.8	7.1		
Carebara vidua [4]	22.2	10.4	51.7	26.2	106.0	10.7	5.7		
RDA for 25 years old male [5]	1000	400	4700	1500	700.0	8.0	11.0	2.3	0.9

[1]Kinyuru et al. (2010a, b), [2]Ssepuuya et al. (2016), [3]Kinyuru et al. (2013), [4]Ayieko and Kinyuru (2012), [5] Bukkens and Poaletti (2005)

Table 4 Vitamin composition and fatty acid fractions of some edible insects in East Africa

Edible insects	Vitamin A (µg/g)	Vitamin E (µg/g)	Vitamin B3 (mg/100 g)	Vitamin B2 (mg/100 g)	Vitamin C (mg/100 g)	Vitamin B9 (mg/100 g)	Vitamin B6 (mg/100 g)	SFA (%)	MUFA (%)	PUFA (%)
Ruspolia differens (green) fresh [1]	2.1	201	2.1	1.2	0.1	0.9	0.4	38.3	26.6	34.4
Ruspolia differens (green) toasted [1]	0.82	139.2	3.3	0.93	0.5	0.6	0.42			
Ruspolia differens (green) fresh dried [1]	0.69	135.9	3.2	0.84	0.35	0.34	0.4			
Ruspolia differens (Brown) fresh [1]	2.8	152	2.4	1.4	0.1	0.9	0.2	39.1	26.3	33.8
Ruspolia differens (Brown) toasted [1]	1.8	160.1	0.12	1.05	3	0.5	0.15			
Ruspolia differens (Brown) fresh dried [1]	1.6	155.5	0.12	0.96	3.01	0.35	0.14			
Macrotermes subylanus fresh dried [1]	1	35.9	2.07	2.3	0.33	0.1	0.24			
Macrotermes bellicosus (dewinged) [3]								49.5	44.6	5.9
Macrotermes subylanus (dewinged) [3]								35.05	52.8	12.2
Macrotermes subylanus (toasted) [1]	1.6	41.4	2.2	2.8	0.5	0.12	0.26			
Pseudacanthotermes militaris (dewinged)[3]								32.2	56.1	11.7
Pseudacanthotermes spiniger (dewinged) [3]								35.8	52.9	11.3
Carebara vidua [4]	0.8	0.6	0.28	20.3	0.03	0.5				

SFA saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acid

[1]Kinyuru et al. (2010a, b), [2]Ssepuuya et al. (2016), [3]Kinyuru et al. (2013), [4]Ayieko and Kinyuru (2012), [5] Bukkens and Poaletti (2005)

Table 5 Amino acid profile of selected edible insects in East Africa (mg/g protein)

Edible insects	Histidine	Isoleucine	Leucine	Lysine	Methionine	Cystine	Methionine + Cysteine	Phenylanine + Tyrosine	Threonine	Trytophane	Valine
Acheta domesticus (adult) [6]	21.0	36.0	66.0	53.0	25.0	9.1	25.0	92.0	35.0	9.0	55.0
Macrotermes bellicosus [7]	51.4	51.1	78.3	54.2	27.5	18.7	26.2	74	27.5	14.3	73.3
RDA for 25 years old male [8]	15.0	30.0	59.0	45.0	16.0	6.0	22.0	30.0	23.0	6.0	39.0

[6]Finke (2002), [7]Bukkens (1997), [8] WHO (2007)

profile, food efficiency ratio and protein efficiency ratio (PER) are some of parameters used in evaluating the biological value of proteins. Grasshopper, with a PER of 1.90 is considered superior to soy and crayfish proteins with a PER of 1.33 and 1.66 respectively (Solomon et al. 2008). *Acheta domesticus* protein has been reported to be superior compared to soy proteins (Nakagaki and Defoliart 1991) based on PER. Edible insects therefore have the potential of being utilized as supplements in the promotion of food and nutrition security.

4 Challenges Associated with the Quality of Nutrients from Edible Insects

4.1 Digestibility

Edible insects have abundant essential nutrients for adequate nutritional contribution to human diets. However, availability of these nutrients is challenged by the unanswered questions on digestibility of the insects in the human gut. Processing/cooking methods either increase or decrease digestibility of some components such as proteins (Opstvedt et al. 2003). For instance there was a decline in *in-vitro* digestibility of proteins of boiled and toasted locusts (Nafisa et al. 2008). *In-vitro* protein digestibility of winged termites, grasshoppers ranged between 81.11% and 90.49% with the fresh sample recording higher value than the toasted, toasted and dried and fresh and dried counterpart (Kinyuru et al. 2010a, b). Protein digestibility of dry pan frying, boiling, and boiling followed by sun drying varied between 34% and 67% in grasshoppers and 46–63% in white ants was reported in Uganda (Mbabazi 2011). More studies therefore need to be done to ascertain the question of protein digestibility.

4.2 Mineral Bioavailability

It has been hypothesised that minerals from edible insects are more bioavailable compared to minerals from plant sources (Christensen et al. 2006) hence could potentially help in reducing deficiencies of public health concern such as iron and zinc (Hongo 2003). However the considerably high iron content of edible insects could be as a result of contamination with soil during harvesting, (Kinyuru et al. 2013) therefore not bioavailable. *In-vivo* studies in Kenya and Cambodia involving young children, showed that the iron status of the children consuming insect based complementary foods did not show marked increase compared to plant based complementary foods further adding to the question of bioavailability of the minerals from edible insects (Skau et al. 2015).

5 Edible Insect Opportunities as Food Throughout the Lifespan

5.1 Preventing and Treating Malnutrition in Children

Malnutrition is the largest contributor to disease in the world (Prudhon et al. 2006; Moreki et al. 2012). Among the Sustainable Development Goals, alleviation of malnutrition is key. There is considerably high levels of malnutrition in East Africa. For instance in Kenya chronic malnutrition among children below 5 years stand at 26% and acute malnutrition is at 4% (KDHS 2014). To attain proper nutrition, there is need for continuous access to quality food and dietary diversity which is essential for proper growth (Rytter et al. 2015).

Micronutrient deficiencies are also common among children, therefore necessitating intake of iron, vitamin A, iodine and zinc, which are vital for child growth and mental development (Prudhon et al. 2006). A study concluded that consumption of 100 grams of toasted longhorn grasshopper could aid meet the recommended daily intake for vitamins such as vitamin A, E, B2, B3 and B9 and also minerals for instance potassium, calcium, zinc and iron (Kinyuru et al. 2010a, b). Current studies have shown that insect based complementary foods are of superior quality as compared to commercially produced complimentary food (Kinyuru et al. 2015).

5.2 Contribution of Edible Insects to Health

The fibre content of edible insects in East Africa is shown in Table 2. Much of this fibre is usually chitin which has been associated with immune defence against parasitic and allergic reactions (Brownawell et al. 2012). Chitin may also function as a prebiotic, which enhances growth of probiotic bacteria while suppressing the pathogenic bacteria in the gut. This could potentially contribute to alleviate intestinal dysfunction and Environmental Enteric Dysfunction, which has attained increasing recognition as an underlying contributor to malnutrition in children in poor living conditions (Keusch et al. 2016). This hypothesis needs to be documented.

6 Conclusion

Edible insects show a great potential of being part of the human diet among communities living within the East African region. The nutrient profile of edible insects for instance protein compares well with known sources such as beef, chicken and fish, as a result, they have the potential of reducing cases of malnutrition and promote good health among populations. However the utilization of edible insects is still highly influenced by traditional postharvest practices. Therefore to promote the use of edible insects both at household and industrial levels, modern and suitable farming, processing and storage methods should be applied.

References

Agea JG, Biryomumaisho D, Buyinza M, Nabanoga GN (2008) Commercialization of *Ruspolia nitidula* (Nsenene grasshoppers) in central Uganda. Afr J Food Agric Nutr Dev 8:291–303

Aguilar-Miranda ED, Lopez MG, Escamilla-Santana C, Barba de la Rosa AP (2002) Characteristics of maize flour tortilla supplemented with ground *Tenebrio molitor* larvae. J Agric Food Chem 50:192–195. https://doi.org/10.1021/jf010691y

Ayieko M (2010) Processed products of termites and lake flies: improving entomophagy for food security within the lake victoria region. Afr J Food, Agric Nutr Dev 10:2085–2098

Ayieko MA, Kinyuru JN (2012) Nutritional value and consumption of black ants (Carebara Vidua smith) from the Lake Victoria region in Kenya. Adv J Food Sci Technol 4:39–45

Ayieko MA, Oriaro V (2008) Consumption , indigeneous knowledge and cultural values of the lakefly species within the Lake Victoria region. African. J Environ Sci Technol 2:282–286

Ayieko MA, Oriaro V, Nyambuga IA (2010) Processed products of termites and lake flies: improving entomophagy for food security within the Lake Victoria region. Afr J Food, Agric Nutr Dev 10:2085–2098

Ayieko MA, Obonyo GO, Odhiambo JA et al (2011) Constructing and using a light trap harvester: rural technology for mass collection of agoro termites (*Macrotermes subhylanus*). Res J Appl Sci Eng Technol 3:105–109

Babiker H, Eltayeb O, Elhassan H (2007) Solubility and functional properties of boiled and fried Sudanese tree locust flour as a function of NaCl concentration. J Food Technol 5:210–214

Braide W, Nwaoguikpe RN, Oranusi SE, Udegbunam LI, Akobondu C, Okorondu SI (2011a) The effect of boideterioration on the nutritional composition and microbiology of an edible long winged reproductive termite, *Macroterms bellicosus*. Smeathman. Internet. J Food Saf 13:150–156

Braide W, Oranusi S, Udegbunam L et al (2011b) Microbiological quality of an edible caterpillar of an emperor moth, *Bunaea alcinoe*. J Ecol Nat Environ 3:176–180

Brownawell AM, Caers W, Gibson GR et al (2012) Prebiotics and the health benefits of fiber: current regulatory status, future research, and goals. J Nutr 124:962–974. https://doi.org/10.3945/jn.112.158147.plant

Bukkens SGF (1997) The nutritional value of edible insects. Ecol Food Nutr 36:287–319. https://doi.org/10.1080/03670244.1997.9991521

Bukkens SG, Poaletti MG (2005) Insects in the human diet: nutritional aspects. In: Ecological implications of minilivestock: potential of insects, rodents, frogs and snails, pp 545–577

Christensen DL, Orech FO, Mungai MN et al (2006) Entomophagy among the Luo of Kenya: a potential mineral source? Int J Food Sci Nutr 57:198–203. https://doi.org/10.1080/09637480600738252

Defoliart GR (1995) Edible insects as minilivestock. Biodivers Conserv 4:306–321. https://doi.org/10.1007/BF00055976

FAO (2010) Forest insects as food: humans bite back. In: Asia-Pacific resources and their potential for development, FAO, Bangkok, Thailand, pp 23–201

FAO (2013) Edible insects. Future prospects for food and feed security. FAO, Rome. pp 1–201

Fasoranti JO, Ajiboye DO (1993) Some edible insects of Kwara state, Nigeria. Am Entomol 39:113–116

Finke MD (2002) Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biol 21:269–285. https://doi.org/10.1002/zoo.10031

Gashe BA, Mpuchane SF, Siame BA et al (1997) The microbiology of phane, an edible caterpillar of the emperor moth, Imbrasia belina. J Food Prot 60:1376–1380

Ghaly AE (2009) Insects as human food in zambia.pdf. J Biol Sci 9:93–104

Hongo TA (2003) Micronutrient malnutrition in Kenya. Afr J Food Agric Nutr Dev 3:1–11

KDHS (2014) Key Indicators 2014 Kenya Demographic and Health Survey (KDHS) Millennium Development Goals for 2015

Kelemu S, Niassy S, Torto B et al (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insects as Food Feed 1:1–17. https://doi.org/10.3920/JIFF2014.0016

Keusch GT, Rosen berg IH, Denno DM, Duggan C, Guerrant RL, Lavery JV, Tarr PI, Ward HD, Black RE, Nataro JP, Ryan ET, Bhutta ZA, Coovadia H, Lima A (2016) Implications of acquired environmental enteric dysfunction for growth and stunting in infants and children living in low and middle income countries. Food Nutr Bull 8:583–592. https://doi.org/10.1002/aur.1474.Replication

Kinyuru JN, Kenji GM, Njoroge MS (2009) Process development, nutrition and sensory qualities of wheat buns enriched with edible termites (*Macrotermes subhylanus*) from Lake Victoria region, Kenya. Afr J Food, Agric Nutr Dev 9:1739–1750. https://doi.org/10.4314/ajfand.v9i8.48411

Kinyuru JN, Kenji GM, Muhoho SN, Ayieko M (2010a) Nutritional potential of longhorn grasshopper *(Ruspolia Differens*) consumed in Siaya District, Kenya. J Agric Sci Technol 12:32–46

Kinyuru JN, Kenji GM, Njoroge SM, Ayieko M (2010b) Effect of processing methods on the in vitro protein digestibility and vitamin content of edible winged termite (*Macrotermes subhylanus*) and grasshopper (*Ruspolia differens*). Food Bioprocess Technol 3:778–782. https://doi.org/10.1007/s11947-009-0264-1

Kinyuru JN, Konyole SO, Roos N et al (2013) Nutrient composition of four species of winged termites consumed in western Kenya. J Food Compos Anal 30:120–124

Kinyuru JN, Konyole SO, Onyango-Omolo SA et al (2015) Nutrients, functional properties, storage stability and costing of complementary foods enriched with either termites and fish or commercial micronutrients. J Insects as Food Feed 1:149–148. https://doi.org/10.3920/JIFF2014.0011

Klunder HC, Wolkers-Rooijackers J, Korpela JM, Nout MJR (2012) Microbiological aspects of processing and storage of edible insects. Food Control 26:628–631. https://doi.org/10.1016/j.foodcont.2012.02.013

Konyole S, Kinyuru JN, Owuor BO (2012) Acceptability of Amaranth grain-based nutritious complementary foods with Dagaa fish (Rastrineobola Argentea) and edible termites (*Macrotermes subhylanus*) compared to corn soy blend plus among young children/mothers dyads in western Kenya. J Food Res 1:111–120. https://doi.org/10.5539/jfr.v1n3p111

Kozanayi W, Frost P (2002) Marketing of Mopane Worm in Southern Zimbabwe. Institute of Environmental Studies, University of Zimbabwe: 1–31

Mbabazi M (2011) Dietary contribution of grasshoppers (*Ruspolia nitidula*) and white ants (*Macrotermes bellicosus*) and influence of processing methods on their nutrient composition (Doctoral dissertation, Makerere University, Uganda)

Moreki JC, Tiroesele B, Chiripasi SC (2012) Prospects of utilizing insects as alternative sources of protein in poultry diets in Botswana. J Anim Sci Adv 2:649–658

Mujuru FM, Kwiri R, Nyambi C et al (2014) Original research article microbiological quality of Gonimbrasia belina processed under different traditional practices in Gwanda. Zimbabwe 3:1085–1094

Musisi NB (1991) Women, "Elite Polygyny," and Buganda state formation. Signs J Women Cult Soc 16:757–786. https://doi.org/10.1086/494702

Nabayo MC, Tenyang N, Tchouanguep F (2012) Nutritional value and effect of cooking, drying and storage process on some functional properties of *Rhynchophorus phoenicis*. Int J Life Sci Pharma Res 2:203–219

Nadeau L, Nadeau I, Franklin F, Dunkel F (2014) The potential for entomophagy to address undernutrition. Ecol Food Nutr 54:200–208. https://doi.org/10.1080/03670244.2014.930032
Nafisa MH, Sara YH, Amro BH (2008) Nutritional evaluation and physiochemical properties of boiled and fried tree locust. Pak J Nutr 7:325–329
Nakagaki BJ, Defoliart GR (1991) Comparison of diets for mass-rearing Acheta dornesticzs (Orthoptera: Gryllidae) as a novelty foodo and comparison of food conversibri efficiency with values reported for livestock. J Econ Entomol 84:891–896. https://doi.org/10.1146/annurev-environ-020411-130608
Omotoso OT (2006) Nutritional quality, functional properties and anti-nutrient compositions of the larva of Cirina forda (Westwood) (Lepidoptera: Saturniidae). J Zhejiang Univ Sci B 7:51–55. https://doi.org/10.1631/jzus.2006.B0051
Opara MN, Sanyigha FT, Okoli (2012) Studies on the production trend and quality characteristics of palm grubs in the tropical rainforest zone of Nigeria. J Agric Technol 8:851–860
Opstvedt J, Nygard E, Tor A, Venturini G, Luzzana U, Mundheim H (2003) Effect on protein digestibility of different processing conditions in the production of fish meal and fish feed. J Sci Food Agric 83:775–782. https://doi.org/10.1002/jsfa.1396
Prudhon C, Briend A, Weise Prinzo Z (2006) SCN Nutrition Policy Paper No. 21 - WHO, UNICEF, and SCN informal consultation on community-based management of severe malnutrition in children. Food Nutr Bull United Nations Univ 27:2010
Ramos-Elorduy (2005) Insects a hopeful food source. In: Ecological implications of minilivestock :potential of insects, rodents, frogs and snails, Science publishers, Inc, Enfield, USA pp 263–291
Rumpold BA, Schluter OA (2013) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57:802–823. https://doi.org/10.1002/mnfr.201200735
Rytter MJH, Namusoke H, Babirekere-Iriso E (2015) Social, dietary and clinical correlates of oedema in children with severe acute malnutrition: a cross-sectional study. BMC Pediatr 15:25. https://doi.org/10.1186/s12887-015-0341-8
Severi S, Bedogni G, Manzieri AM et al (1997) Effects of cooking and storage methods on the micronutrient content of. foods 6:521–524
Skau JKH, Touch B, Chhoun C et al (2015) Effects of animal source food and micronutrient fortification in complementary food products on body composition, iron status, and linear growth: a randomized trial in Cambodia. Am J Clin Nutr 101:742–751. https://doi.org/10.3945/ajcn.114.084889
Solomon M, Ladeji O, Umoru H (2008) Nutritional evaluation of the giant grasshopper (Zonocerus variegatus) protein and the possible effects of its high dietary fibre on aminoacids and mineral bioavailability. Afr J Food Agric Nutr Dev 8:238–251
Ssepuuya G, Mukisa IM, Nakimbugwe D (2016) Nutritional composition, quality, and shelf stability of processed *Ruspolia nitidula* (edible grasshoppers). Food Sci Nutr:1–10. https://doi.org/10.1002/fsn3.369
van Huis A (2003) Insects as food in sub- Saharan Africa. Int J Trop Insect Sci 23:163–185
van Huis A (2015) Edible insects contributing to food security? Agric Food Secur 4(20). https://doi.org/10.1186/s40066-015-0041-5
WHO (2007) Protein and amino acid requirements in human nutrition: World Health Organization technical report series 935. United Nations University
Yen AL (2015) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insects as Food Feed 1:33–55. https://doi.org/10.3920/JIFF2014.0017

Edible Insects in a Food Safety Perspective

Simone Belluco, Alberto Mantovani, and Antonia Ricci

Abstract Food safety aspects of edible insects are largely unknown but their widespread consumption worldwide supports the possibility of their consumption. In recent years the interest toward insects as food has grown also in countries with no previous experiences of consumption, where their diffusion was limited by legislative barriers or by the absence of specific rules laying them in a grey area. Evidence from traditional practises are useful to identify species suitable for human consumption and to exclude major food safety risk. However, tradition alone could not satisfy the need of data to set a proper legislation able to guarantee consumer safety. Data about biological and chemical risks are needed to appropriately manage potential risk deriving from insect farming and consumption along the food chain, with particular regard to the rearing substrate. Aim of this chapter is to discuss the value of current evidences about food safety of edible insects in the context of modern food safety system, to highlight data gaps and to suggest the need for further research.

1 Introduction

Safety is a necessary condition for a substance to be considered as food as "if it is not safe, it is not food". Consequently, food security, that represents a constant challenge especially in developing countries, has to be guaranteed through the availability of safe food. Food safety is often seen in contrast with food security as the first is devoted to the "selection" of food based on safety parameters, whereas the second aims at maximizing food availability, through the widening of food sources and the reduction of food waste. However, food safety and food security go in the same direction: making (safe) food available to humans, worldwide. This is

S. Belluco (✉) · A. Ricci
Istituto Zooprofilattico Sperimentale delle Venezie, Legnaro (PD), Italy
e-mail: sbelluco@izsvenezie.it; aricci@izsvenezie.it

A. Mantovani
Istituto Superiore di Sanità (ISS), Rome, Italy
e-mail: alberto.mantovani@iss.it

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_7

particularly true for malnourished subjects who are more susceptible to the consequences of food-borne diseases.

The case of edible insects lays in this context as insects are suggested as a potential solution to increase protein availability with advantages in terms of sustainability and ease of farming. On the other side, their potential is currently limited by the lack of data clearly demonstrating their safety of consumption. The lack of scientific data is of particular concern for countries with no previous dietary traditions for consuming insects. In most of these countries edible insects lay in a grey legislative area due to the lack of specific requirements and the need to frame them within existing rules.

In the last years several reviews have summarized available evidence about the food safety aspects of edible insects and important data gaps emerged (Belluco et al. 2013, 2015; Rumpold and Schlueter 2013; van der Spiegel et al. 2013; Mlcek et al. 2014). Besides possible food safety issues, a main problem for widespread acceptance of edible insects is that insects are traditionally considered as pests of primary production systems and vectors of biological contamination within farms and processing plant. Consequently, most available studies refers to this attribute of insect presence along the food chain and the value of their evidence is reduced when the scientific context is changed. Available evidences suffer also by the species being investigated as their selection is driven by their potential to act as vector of disease and not by their potential to be source of food.

Discussion about "species" is relevant as the insect class (Insecta, Linnaeus 1758) accounts for thousands of species worldwide with hundreds of them being traditionally consumed in several countries (Jongema 2015) and it is impossible to define their safety without taking into account differences across taxonomical levels.

According to the Codex Alimentarius (a collection of international food standards, guidelines and codes of practice that contribute to the safety, quality and fairness of international food trade WHO/FAO) the international recognized definition of food is "any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance which has been used in the manufacture, preparation or treatment of "food" but does not include cosmetics or tobacco or substances used only as drugs" (FAO/WHO 2010).

Insects intended for human consumption are undoubtedly food, if safe. But are they safe? This question needs to be answered before the food is placed on the market according to the food laws of several countries worldwide (Constable et al. 2007).

The salient point of edible insects legal recognition as food goes beyond insects themselves, as it is about assessing the safety of a "new food" in general. The legislative experiences of different countries show that a two way solution exists: (i) an "epidemiological way", which takes into account the experiences of people already consuming the "new" food, and (ii) an "analytical way", based on the analysis of the new food to get primary data to perform a risk assessment considering all potential hazards and allowing risk managers to take decisions.

The "epidemiological way" relies on the availability of experiences of consumption showing the lack of safety risks due to this practise. The main challenges within this way are: (i) the definition of the amount of experience needed to advocate a history of consumption and (ii) the information needed to ascertain the safety of this consumption in the light of public health protection status of each country.

The analytical way relies on experimental proofs of safety and requires not only the identification of potential hazards but also the definition of consequent risks for consumers. Hazards can range from biological agents, such as virus and bacteria, to chemical contaminants.

It is worth mentioning that every attempt to discuss edible insects safety needs to address the difference between farmed and wild harvested insects. In the first case it is possible to advise insect farmers about which hazards should be controlled, limiting the potential negative consequences for consumer health. In the second case hazards potentially arising from the consumption of wild insects are unpredictable as environment and feed are parameters out of control.

The aim of this chapter is to frame farmed edible insects in the context of the food safety topic explaining the challenge of their recognition as food. The first part provide a description of the context in which the "epidemiological way" should operate with some basic concepts about how food safety works and about the approach of different legislation worldwide. In the second part the current knowledge about biological and chemical risks is described. Finally edible insects safety is discussed in the context of available evidences with the identification of challenges, opportunities and potential pitfalls.

2 Epidemiology of Insect Consumption

Several countries worldwide have a specific legislation on Novel Food, where novelty is generally qualified as the absence of a country-based history of consumption. The concept of "history of safe consumption" is hard to define, as it is not based on a standardized list of criteria. To define the safety of a food it is required to define: the period over which the traditional food has been consumed, the way of preparation and use, the intake levels, the composition and the results of animal studies and observations from human exposure (Constable et al. 2007). For this reason the framing of new substances intended for human consumption is all but simple. An important decision up to legislators within this kind of regulation is about the origins of the tradition. As an example, under the current European legislation (Reg. EC 258/1997 applicable until January 2018) the validity of the concept of tradition is limited to Member State's territories, but from 2018 also the tradition from third countries will be considered (Reg. EC 2015/2283) if the history of safe use is consistently documented (EFSA 2016). In Canada the validity of the "safe use" is weighted on the basis of the ability of the country of origin to satisfy Canadian food safety standards (Halloran et al. 2015).

Experiences of insect consumption are widespread in Africa, Asia and South America but experience is not science. Science is based on sound experiences able to represent and describe reality without prejudice. How far experiences of consumption can demonstrate the safety of a novel food? This is the question.

In the EU, to frame edible insects within the regulatory context, the European Commission asked EFSA to assess the potential risk deriving from insect consumption. Due to the insufficient amount of data for a risk assessment purpose EFSA carried out an initial risk profile for edible insects (EFSA 2015) which means a description of the food safety problem and its context (FAO/WHO 2010). A risk profile represents the first step to identify potential hazards calling for further evidence.

Once hazards have been identified, Food Safety Objectives (FSO) are needed. FSO define the maximum frequency and/or concentration of a hazard in a food at the time of consumption that provides or contributes to the Appropriate Level of Protection (ALOP) (Gkogka et al. 2013). ALOP is "*the level of protection deemed appropriate by the Member (Country) establishing a sanitary or phytosanitary measure to protect human, animal and plant life or health within its territory*". From a practical point of view ALOP represents a country's currently achieved public health status in relation to food safety (EFSA 2007).

Following these considerations it is possible to state that food safety is not a general concept, but is based on a country public health status, thus a mutual recognition among countries is not easy way, despite the efforts of the WTO and the Codex Alimentarius Commission to harmonize international standards.

In this context it is possible to discuss the proposal to rely on the experience of safe consumption from third countries to assess the safety of a food. Data about the safety of consumption are needed to allow a sound evaluation of the potential hazards and decide for the market permissions when consumer protection can be guaranteed. In Europe specific guidelines have been prepared by EFSA to support stakeholders willing to notify the introduction in the EU of a "Traditional Food from third countries" as defined by Reg 2015/2283. Among the requested information applicants should *document their comprehensive literature search for available human data related to the safety of the traditional food (e.g. kinetic data, toxicological, nutritional, microbiological, allergenic, tolerability, interaction with medicines).* Food safety data are needed not only to support the safety of a food but also to allow the implementation of specific criteria able to guarantee consumers throughout the food chain (EFSA 2016).

In the USA edible insects fall under FDA activities and are considered food under the Food, Drug and Cosmetic Act (sec. 201f) if this is their intended use, providing that their production respects general regulation in place for food and that they are clean and wholesome.

3 Analytical Way

3.1 Biological Hazards

The assessment of biological hazards potentially affecting insects for human consumption suffers from the previously described lack of data. Data about the microbiology of insects exist in scientific literature, but in the majority of cases the aim of researchers was not the study of insects in the light of human consumption. The main focus in most published papers is about the understanding of insects as vectors of diseases in animal farms (Wales et al. 2010) or about a qualitative description of the microbial community of different, often wild, species.

Hazards to be considered when discussing the safety of a food are: virus, bacteria, parasites and prions. Each of these categories of hazards should be addressed to cover the topic of biological risks.

Insects have a specific plethora of viral pathogens, representing a high risk for crowded insects farms, that need consideration from an animal health perspective. However, these viruses are considered safe for humans and even, in some cases, approved as biocontrol agents in agriculture. Human viruses with a taxonomical relation to insect ones have been shown to be unable to replicate in insects (Eilenberg et al. 2015). Viruses with a well-known ability to replicate in insects are arthropod-borne viruses (arboviruses) able to cause disease in humans (Dengue, West Nile disease, Rift Valley Fever, Haemorrhagic Fever, Chikungunya).

Even in this context it is important to remind the need for a species by species discussion, and focusing on insect species intended for human consumption in countries without a consolidated tradition, the vectorial competence has never been demonstrated (Eilenberg et al. 2015). However, it is not possible to exclude that some viruses could be introduced in insects farms by substrate with the potential to be transferred beyond primary production, and with the need for prevention strategies or processing criteria (Eilenberg et al. 2015). Thus, in the case of viruses, the pillars to discuss food safety aspects are species and substrate.

Moving to the bacterial hazards, evidence exists about the potential for insects to be mechanical (Goodwin and Waltman 1996; Nelson and Harris 2006; Ahmad et al. 2007; Agabou and Alloui 2010) or biological (Kobayashi et al. 1999; Templeton et al. 2006; Hazeleger et al. 2008) vectors of pathogenic micro-organism. However, the ability of insects to act as reservoir of such microorganisms as well as the existence of vertical transmission, are not well known. These conditions are of utmost importance as they represent factors with a potential to maintain bacteria within dedicated farms.

According to EFSA's recent opinion defining the risk profile of edible insects, two types of microbiota should be considered: intrinsically associated microorganisms and those that are introduced during farming and processing and carried forward (EFSA 2015).

Regarding intrinsic bacteria, the microbial community of mealworm larvae (*Tenebrio molitor*) and grasshopper (*Locusta migratoria migratorioides*) for human consumption has been recently described. Results showed high levels of total viable aerobic and Enterobacteriaceae counts in analysed batches. Bacterial spore counts where highly variable among batches. Proteobacteria, Firmicutes and Actinobacteria dominated the bacterial composition of mealworm larvae, and Firmicutes and Proteobacteria of grasshoppers. Abundant OTUs of genera such as Haemophilus, Staphylococcus and Clostridium, which can contain pathogenic species, were found in mealworm larvae (Stoops et al. 2016).

The potential detection of pathogens at farm level is not a sufficient condition to rule out the introduction of insects in human diet. In the farm to fork chain, several stages beyond primary production are able to face the pathogenic presence restoring safety conditions, as normally happens for other commonly consumed animal products. In a study addressing edible insect in a food safety perspective, Klunder et al., analysed the effect of different processes in various combinations (fresh, boiling, roasting, storing) on the microbial community of mealworm (*Tenebrio molitor*) and cricket (*Acheta domesticus* and *Brachytrupes* sp.). Results showed that storage at refrigeration temperature was required for boiled insects but was ineffective for fresh insects. Roasting alone was considered partially ineffective and performed better when paired with boiling. Also lactic acid fermentation was able to inactivate Enterobacteriaceae and keep remaining sporeforming bacteria stable at acceptable levels where they were unable to germinate and grow (Klunder et al. 2012). Despite the lack of specific criteria to assess the microbiological quality of insects some recent studies carried out in the EU tried to use existing microbiological criteria for meat laid down in Reg. (EC) 2073/2005 and following amendments, as proxy of specific but not existing ad hoc criteria. A small-scale survey on the microbiological status of 55 freeze-dried insect based products (locusts, lesser mealworms, mealworms and a mealworm snack), found that more than half (59%) of tested samples exceeded the process hygiene criterion of 10^6 cfu/g for aerobic bacteria in raw materials used in meat preparation. In 65% of cases the criterion of 10^3 cfu/g for Enterobacteriaceae in raw materials used in meat preparations was also exceeded. As regards foodborne pathogens: *Clostridium perfringens*, Salmonella and Vibrio were never isolated and *Bacillus cereus* was less than 100 cfu/g in the 93% of samples (Netherlands Food and Consumer Product safety authority 2014). Counts of indicator bacteria with numbers above the process hygiene criteria was observed also by Stoops et al. on mealworm larvae and grasshoppers.

What emerges from existing evidence is the need for strategies aimed at reducing the contamination with hygiene indicator bacteria as also the need to keep sources of pathogenic bacteria away from insects during the whole production life cycle. In particular it is of great importance to ascertain the microbiological quality of substrate. This because even if evidences claiming the low survival of bacteria within insects are confirmed, substrate could be an important source of contamination.

Regarding parasites, once again, existing evidence are limited to epidemiological case reports and are unlikely to give a complete picture of reality useful in a risk assessment perspective. From human autopsies and insect analyses, in areas were insects consumption is traditionally practised, it has been noticed that parasites (trematodes) belonging to the family Lecithodendridae and Plagiorchidae are likely to be transmitted through the oral route (Chai et al. 2009).

Several cases of infestation with *Gongylonema pulchrum* are reported in scientific literature with a worldwide distribution and an occasional association with the ingestion of raw insects (Molavi et al. 2006; Allen and Esquela-Kerscher 2013).

Some parasites should be re-evaluated in the context of this novel protein source, as in the case of *Dicrocoelium dendriticum.* This trematode is the causative agent of a rare food-borne zoonosis of the human biliary tract known to be transmitted by the ingestion of infested liver of ruminants (pseudodicrocoeliosis). Despite the potential for humans to be infested by other definitive hosts such as cow, its epidemiological role in the parasite life cycle is of definitive hosts, thus the ingestion of infested ants (intermediate hosts) causes human dicrocoeliosis (Jeandron et al. 2011).

The potential oral transmission of *Trypanosoma cruzi i*s noteworthy as this parasite is responsible of the Chagas disease and affects about 10 million people in the Americas, with more than 10,000 people dying each year. Poor housing conditions promote contact with infected vectors and, even though the oral route is not the main way of transmission, cases have been reported in the literature linking infection with the accidental ingestion of insects (Pereira et al. 2010) or consumption of contaminated food (Trotta Barroso Ferreira et al. 2016).

Some insects species (*Blatella germanica and Periplaneta americana*) have been demonstrated to harbour pathogenic protozoa like *Entamoeba histolytica*, *Giardia lamblia, Toxoplasma spp. and Sarcocystis spp.,* but only for a limited time.

Another relevant biological hazard is represented by prions whose potential role in insects has been extensively discussed in the EFSA risk profile. Specific prionic diseases have not been observed in insects due to the lack of a PrP-encoding gene. This finding, however, does not rule out the possibility for insects to act as vector of prions deriving from at risk substrates of ruminant origins with potential concerns for humans or susceptible animals. The risk can be controlled by avoiding the feeding of insects with such materials, avoiding the use of insects as feed of susceptible species or appropriately treating such materials to inactivate prions (EFSA 2015).

The increased focus on insect rearing is very much based on the potential of insects to convert organic material of low quality into high quality food and feed. Therefore, there is an interest for potential use of low-cost types of organic materials as substrate, thus strongly influencing the final microbiological quality of end products (EFSA 2015).

The substrate where insects are fed as also the farming environment strongly influence insects' microbiota, therefore the foodborne risk is influenced by the nature and the hygienic conditions of the substrate and the farming environment (EFSA 2015). A wide range of organic materials can be used as source of nutrients or as substrates for rearing of insects. The substrates that will be included in the production will depend on the legislative framework, availability, the applicability in the specific farming system and the cost. Due to the different requirements, the substrate preference will differ among the different insect species.

Both these microbial communities are correlated with species and farming conditions. Among farming conditions feeding practices play the most important role as feed in most cases is the substrate that allows insects to carry out their life cycles. If insects are potential mechanical vector of diseases and substrate is the matrix with a likely high influence on insect microbiota, feed microbial conditions are crucial aspects in the management of insect farms and the legal effort to frame the production of this new protein source cannot neglect this aspect.

3.2 Chemical Hazards

Chemical hazards in edible insects include (i) endogenous substances and (ii) undesirable substances and contaminants in insect feeding and farming; in addition the safety assessment of edible insects as feeds calls for some general considerations on the identification of specific and critical hazards in the farming of animals intended to produce novel foods.

3.2.1 Endogenous Substances

Albeit not "toxic" substances strictly speaking, allergens should be briefly mentioned amongst endogenous components in edible insects that pose concerns to consumer safety. Whereas allergy to insect-derived antigens mostly occurs in humans through inhalation of dust or contact, the occurrence of allergic reactions upon ingestion is well documented. There are indications that people who are allergic to crustaceans and shellfish and/or dust mites could have an allergic reaction to the consumption of insects, also due to cross-reactivity (Verhoeckx et al. 2014); indeed, new insect allergens are sometimes identified (Srinroch et al. 2015). The presence of chitin may represent an allergenic hazard, *per se*, as shown by research in murine models as well as by the high prevalence of asthma among people working with chitinous substances, such as crabs and fungi, its intake has been associated to asthma (Brinchmann et al. 2011). Conversely, there is no evidence about the prevalence of allergies to insect-derived antigens in communities traditionally consuming edible insects.

Insect venoms mostly include defensive mechanisms, such as the production of carbon acids, alcohols, aldehydes, phenols. These substances are mainly local irritants, but some may have significant systemic effects, such as alkaloids, steroids, cyanogenic glucosides or the (benzo)quinones and alkenes produced by Tenebrionidae. Insects of concern for consumer safety are cryptotoxic: they contain toxins as a consequence of synthesis or accumulation, do not possess an external secretary apparatus and are toxic only after being ingested. However, the edible insects considered in Europe are not known as toxic (EFSA 2015). In the last years some studies investigated the safety of edible insects as whole foods by means of repeated dose toxicity studies in rats: *Allomyrina dichotoma* larvae (Noh et al. 2015), yellow mealworm (Han et al. 2016). These studies investigated dose levels up to 2500–3000 mg/kg body weight (bw)/day and the detailed toxicological assessment included also potential hypersensitivity: no treatment-related adverse effects were identified. In addition, the freeze-dried powder of yellow mealworm showed no genotoxic activity *in vitro* or *in vivo* (Han et al. 2014). The absence of genotoxicity *in vitro* was confirmed also for water soluble extracts of two insects commonly eaten in Nigeria, *Zonocerus variegatus* and *Oryctes boas,* even though both extracts increased oxidative stress in vitro (Memiş et al. 2013). The available studies, therefore, support that edible insects are unlikely to contain toxic endogenous substances to an appreciable amounts.

Some insect species or products can be rich sources of trace elements, such as copper, iron, magnesium, manganese, phosphorous, selenium, and zinc (Rumpold and Schlueter 2013). Crickets has higher levels of iron, calcium and manganese than grasshoppers, mealworms, and buffalo worms, and similar to that of sirloin beef. Iron from crickets has higher *in vitro* bioaccessibility as compared to that from beef (Latunde-Dada et al. 2016). Whereas this characteristic may be viewed favourably from the nutritional viewpoint, several essential trace elements (e.g., manganese and selenium) have a recognized human toxicity at excess intake levels. Thus the endogenous contents of chemical elements in edible insects should be characterized, as well as the possible modulation by feeding and/or farming conditions.

Last but not least, an overlooked issue till now is represented by process contaminants. Indeed, it is not known whether, and how much, endogenous components of edible insects can form toxic substances, such as polycyclic aromatic hydrocarbons, during processing, e.g. cooking. Polycyclic aromatic hydrocarbons are formed, e.g., during the over-grilling or the smoking of meat and may pose significant health concern due to carcinogenic and/or endocrine disrupting (dioxin-like) hazards (EFSA 2008). Therefore, more data on this issue will allow to define good practices aimed at risk reduction if needed, as well as to compare the possible exposure to process contaminants from insects and from other foods.

3.2.2 Undesirable Substances and Contaminants in Insect Feeding and Farming

Feeding substrates for insects may contain detectable levels of environmental contaminants capable to bioaccumulate: heavy metals, chemical elements such as selenium, dioxins and other organochlorines, and polybrominated diphenyl ethers (EFSA 2015 and references herein).

As for heavy metals, transfer from substrates (e.g. organic matter, plants) to insects is apparently the most important route of contamination. Accumulation is dependent on insect species, growth stage, and metal in question (EFSA 2015). Overall, the bioconcentration of toxic elements, like lead and cadmium, seems a prominent toxicological hazard as regards the safety of insects as foods or feeds in Europe and elsewhere (Vijver et al. 2003; Banjo et al. 2006; EFSA 2015). The consumption of home-prepared dried grasshoppers (chapulines) was a plausible factor of chromic lead poisoning in California: lead concentrations in chapulines were highly variable, but could reach levels as high as 2500 mg/kg (Handley et al. 2007). A recent study of the chemical safety of farmed insects (Charlton et al. 2015) analysed house fly (*M. domestica*), blue bottle (*Calliphora vomitoria*), blow fly (*Chrysomya* spp.) and black soldier fly (*H. illucens*) reared using a variety of substrates and production methods at different geographical locations: the results pointed out cadmium bioconcentration as a potential problem to be further assessed. Noticeably, cadmium accumulation is greater in larval stages (which are often the edible lifestage, as in the case of mealworms) than in adults (Zhuang et al. 2009). Methyl-mercury has been recently observed to bioaccumulate in dragonflies (Buckland-Nicks et al. 2014), with significant differences among species and lifestages: the authors concluded that dragonfly adults retain a high potential for transferring substantial amounts of methyl-mercury to their predators. The relevance of methyl-mercury accumulation to farmed edible insects cannot be ruled out altogether, calling for more research. Further toxic elements might be considered depending on substrates: bogong moths (*Agrotis infusa*), a traditional food item in Australia, were shown to take up arsenic from arsenic polluted soils (Green et al. 2001).

Insects as whole organisms might be poor bioaccumulators of lipophilic pollutants (e.g., dioxins, polychlorinated biphenyls - PCB, polybrominated diphenyl ethers - PBDE); however, the concentration of such pollutants might substantially increase in fat extracts. Dioxins and dioxin-like PCB are assessed and monitored cumulatively, since they all act through the same mechanism (interaction with the aryl hydrocarbon receptor, leading to endocrine disruption and tumour promotion): conversely the potency of the individual compounds is very different, thus each dioxin and dioxin-like PCB is assigned a Toxicity Equivalency Factor (TEF) representing the "weight" to be attributed to a given dioxin-like substance. The sum of dioxin and dioxin-like PCB levels with their TEF gives the Toxicity Equivalent (TEQ) within a mixture contaminating a food commodity or a feed; brominated dioxins and similar compounds may also add up to the total TEQ of dioxin activity (van den Berg et al. 2013). Dioxins and dioxin-like PCB analysed in farmed insects ranged from 0.23 to 0.63 ng TEQ/kg dry weight (Charlton et al. 2015). In the absence of specific limits for edible insects, the European Food Safety Authority (2015) noted that these figures are below the EU maximum content in feed materials of animal origin (1.25 ng WHO-PCDD/F-PCB-TEQ/kg, considering 88% dry matter). Noticeably, there are no data on the potential bioaccumulation of non-lipophilic persistent pollutants, such as perfluoroalkylated substances.

Contrary to other foods of animal origin, edible insects may be liable to mycotoxin contamination when handled or stored at sub-optimal conditions: low levels of the potent carcinogen Aflatoxin B1 were found in the edible stink bug (*Encosternum delegorguei*, widely consumed in southern Africa) stored in recycled grain containers (Musundire et al. 2016). Conversely, the transfer of deoxynivalenol from wheat as substrate to mealworm larvae was found to be very low, except when the substrate was spiked with high concentrations of the mycotoxin (van Broekhoven et al. 2014).

Edible insects such as locusts and mealworms are fed exclusively or partly on fresh vegetables. Residues of pesticides, mainly insecticides, present in such vegetables within the legal limits established for human consumers are unlikely to pose a concern for people consuming insects. However, further information might be desirable on the possible accumulation of pesticides in edible insects upon prolonged intake. In controlled experiments, *Tenebrio molitor* larvae (mealworms, a popular edible insect worldwide) showed a low bioaccumulation of the triazole epoxicolazole (Lv et al. 2014) but were able to accumulate of the phenylamide metalaxyl (Gao et al. 2013); as in vertebrates, the potential for bioaccumulation is partly related to the chemical properties of a given xenobiotic. However, there are no information whether the same edible insects might bioconcentrate pesticide residues in realistic scenarios. A recent, comprehensive survey of 393 pesticide residues in farmed insects (house fly, blue bottle, blow fly and black soldier fly) found only occasional samples above the levels of detection (Charlton et al. 2015).

As a concluding remark, the great differences in anatomy, metabolism and feeding among insect species are likely relevant to risk assessment, e.g., different feeding substrates and/or different ability to metabolize/excrete toxic substances are directly relevant to consumer exposure. In general, for insects with a short life cycle, entraining a limited period of substrate feeding, bioaccumulation is less likely to occur than in insects that are reared over a longer time period. In addition, insect consumption worldwide encompasses adults as well as larval stages and eggs. In many insect species larvae and adults are so different as to appear as different species; thus, many relevant metabolic characteristics may show significant differences between life stages, including the ability to metabolize or accumulate toxicants, as observed for cadmium (Zhuang et al. 2009).

Finally, the potential uptake of toxic metals and other pollutants by the farmed insects through the rearing environment (dust, litter) is worth investigating, even though it seems to have received no attention until now.

3.2.3 Discussion: Setting Regulatory Limits for Chemical Hazards in Edible Insects

According to the European food safety framework, the farming of insects as food and/or feed represents an emerging issue whose assessment calls for further investigation and additional data collection. When consumption of edible insects is identified as posing new, and previously unrecognised hazards, or to lead to a significantly increased exposure to recognized hazards, then it should to be considered as an emerging risk (EFSA 2014).

Following the above distinction between endogenous and exogenous hazards, the recent scientific literature reports some studies where the toxicity of edible insects as whole foods (including the potential for hypersensitization and genotoxicity) is tested, as required also by the regulatory framework on novel foods (Memiş et al. 2013; Han et al. 2014, 2016; Noh et al. 2015): the results, indeed, are quite reassuring, as no adverse effects were identified. On the other hand, it has to considered that the insect world provides a considerable biodiversity, and that edible insects do include larval as well as adult lifestages, which can be completely different. Thus, each species/lifestage proposed for consumption should undergo a separate safety assessment. In addition, given the current lack of definition of "tolerable intakes" for insect venom (which would be a demanding task), venomous insect species or life stages should not, in principle, be farmed for food/feed.

As for exogenous contaminants, the available data point to a prominent role for toxic chemical elements. Most importantly, the characterization and control of the feeding substrate appears as the critical aspect in order to manage or reduce the burden of exogenous environmental chemicals in edible insects. For instance, insects that require a vegetable substrate might be exposed to pesticide residues. The use of organic residual flows and similar materials, in order to increase the economic and environmental sustainability of insect farming, might lead to the bio-concentration of toxic pollutants. Data on transfer of chemical contaminants from different substrates to the different insect species and lifestages are currently too limited to derive maximum tolerable limits. A related issue is the uptake from feed substrates of some essential elements that are required by humans and animals at very low doses, but can be toxic at excess intakes (e.g., selenium, cobalt, molybdenum). For such elements maximum legal levels in feeds are already in place in the EU; however, research is needed to assess the appropriateness of the current levels also for insect feeding substrates. Indeed, in its assessment of chemical contaminants in insects, the European Food Safety Authority (2015) has pragmatically used existing maximum residue levels in other foods or feeds to identify possible critical issues in edible insects.

Finally, like other farm animals, farmed insects will require treatments with drugs, mainly to counteract infections. Thus, antibiotics, fungicides and antiprotozoal drugs will likely the most relevant mass treatments to be performed via feed, water and/or air. However, there are no data sets to assess maximum treatment doses, maximum residue levels or withdrawal times.

Indeed, honey represents a most traditional insect-derived food worldwide; there is substantial scientific evidence on the transfer of residues and contaminants to honey, and this food item is included in the official food monitoring programs. However, the experience gained on honey, a highly peculiar metabolic product of honeybees, can be of limited help, if any, to derive regulatory limits in edible insects, which would provide their bodies (“meat”) as human food or as feedingstuffs for food-producing animals.

The assessment of chemical hazards in edible insects requires systematic investigations in order to cope with the major knowledge gap on the bioavailability and deposition of contaminants and residues in main edible insect species, and their lifestages.

In particular, research should address:

– Species- and lifestage-related differences in the accumulation of contaminants.
– Transfer rates of relevant chemicals from feeding substrates to edible insects.
– Impact of processing methods on the content of residues and contaminants, including process contaminants.

In addition, setting regulatory levels (including maximum residue levels) for any veterinary drug will require estimates of the likely intakes by consumers. Waiting for more scientific evidence, the use of existing regulatory thresholds at least for priority pollutants (e.g., heavy metals) could be a pragmatic choice (EFSA 2015). Another pragmatic possibility could be the use of Reference Points for Action (RPAs), currently adopted for non-allowed pharmacologically active substances present in food of animal origin: a RPA is an analytical concentration that can be determined by official control laboratories and is low enough to adequately protect the consumers of food commodities that contain that substance (EFSA 2013). Finally, as already mentioned, the setting of criteria for feeding substrates would be at least as important as setting maximum residue levels in products in order to guarantee the safety for consumers of edible insects.

4 Discussion

Species, substrates, life stage and consumption are supposed to be the factors affecting the safety of edible insects and derived products, both for biological and chemical hazards, as discussed in sections 3.1 and 3.2. Available evidences have mostly two origins: experience of consumption and scientific literature. The first kind of evidence can be useful for approval purposes, when a history of safe consumption is documented, but can hardly be used to manage potential risk along the production chain, to set regulatory limits or to support the need of information for consumers. The second kind of evidence would allow a proper management of food risk, but, currently, is not sufficient and can be used only for qualitative considerations as done for example by EFSA (2015) and by others national authorities (FASFC Scientific Committee 2014; Netherlands Food and Consumer Product safety authority 2014; ANSES 2015).

At the beginning of insects approval pathway as food, in countries where no such tradition exists, the main challenge could be the identification of species fit for human purposes. This choice can be done by legislator or let to applicants. In the USA edible insects are allowed to be consumed as food if they are fit for purpose, and their production process is in line with food safety requirements. In the EU some Member States (i.e. Belgium and Netherlands) due to the lack of explicit rules, decided to "tolerate" whole insect consumption and shortlisted 10 species fit for purpose, on the basis of traditions and rearing experiences. The EU position, made explicit in the new Novel Food regulation (2015/2283), is to consider insects as Novel Food and to start a case by case evaluation process following stakeholders formal requests. Switzerland included three species of insect (T*enebrio molitor, Acheta domesticus and Schistocerca gregaria)* in its new list of food opening the market for their commercialization and consumption from may 2018.

According to existing legal experiences the choice of insect for human consumption is based on species. This would probably lead to a number of species approved within some years from now, but would not allow to a rapid increase in the number of species allowed for human consumption. A good solution to apply taxonomical considerations to the approval process could be the Qualified Presumption of Safety approach as suggested by Engel and others (2011) (Engel et al. 2011). QPS is an assumption based on reasonable evidence and qualified to allow certain restrictions. In essence, this proposes that a safety assessment of a defined taxonomic group (e.g. genus or group of related species) could be made. If the taxonomic group did not raise safety concerns, or if safety concerns existed but could be defined and excluded (the qualification), the grouping could be granted QPS status. Once a taxonomical group has been granted QPS status, each organism that could be unambiguously established and assigned to that QPS group would be freed from the need for further safety assessment other than satisfying any qualifications specified.

Another important issue is the development of intensive insect rearing facilities requiring the use of antimicrobials to preserve animal health. This administration, if necessary, could raise some concerns in the light of antimicrobial resistance spread. However, currently it is not possible to foresee its application in insect farms and its contribution to the already high antimicrobial selective pressure on bacteria due to intensive farming systems of commonly consumed livestock species.

The problem of traceability and fraud detection is worth mentioning. Are official control authorities able to identify insect species to determine their fitness for consumption (as in the case of mushrooms or fish)? And are the current food safety system able to identify insect species when in the form of meal? This is a salient point that in part exists also for other kind of meat, but that can be addressed by appropriately validated laboratory molecular techniques.

To conclude, the increasing world population and the shift of dietary patterns call for an increase in environmentally sensitive food production. Novel foods, such as insects, are not the solution but probably one of the possibilities that should be pursued to widen food sources in the light of sustainability and small scale, low investment farming systems, provided that they are safe. Experiences of insects consumption as food are widespread and can help in the identification of species fit for human consumption. However such evidence are not able to provide data to allow a proper risk management, as commonly done within the food safety system of national institution worldwide. Further research is warranted to build this data-base. Particular attention should be posed to species selection and substrate. Small-scale farming should be encouraged whereas the feasibility of intensive farming facilities should take into account the potential for antimicrobial use Table 1.

Table 1 List of edible insects chemical and biological hazards, as discussed in this chapter. Each hazard is matched with factors potentially affecting its occurrence according to available scientific evidence

		Notes	Hazards (non exahustive list)	Species	Life-stage	Substrate	Farming conditions	Crowding	Post-harvest treatments
Biological hazards	Virus	Insects' virus unable to replicate in humans	–	Vectorial competence (es. arbovirus)	–	×	×	×	×
	Bacteria	Evidence suggests ability as mechanic vectors, inconclusive about biological vector ability and about vertical transmission	*Salmonella, Clostridium, Vibrio, Bacillus cereus, Campylobacter,*	Unknown	–	×	×	×	×
	Parasites	Farming can interrupt life cycle	*Gongylonema, Dicroecelium, Toxoplasma, Giardia.*	Vectorial competence (ants and dicroecelium)	×	×	×	×	×
	Prions	No insect-specific prions have been demonstrated	–	–	–	×	–	–	–
Chemical hazards	Allergens	Potential for cross-reaction	Tropomyosin, chitin	×	–	–	–	–	–
	Endogenous substances	Accumulation of toxicants (criptotoxic insects) and venoms	Alkaloids, steroids, cyanogenic glucosides or the (benzo)quinones and alkenes.	×	×	–	–	–	–
	Contaminants	Contamination or treatments	Heavy metals (Pb, Cd,…), selenium, dioxins and other organochlorines, polybrominated diphenyl ethers, mycotoxins, pesticides, antimicrobials	×	×	×	×	–	×

References

Agabou A, Alloui N (2010) Importance of Alphitobius Diaperinus (panzer) as a reservoir for pathogenic bacteria in Algerian broiler houses. Vet World 3:71–73

Ahmad A, Nagaraja TG, Zurek L (2007) Transmission of Escherichia Coli O157:H7 to cattle by house flies. Prev Vet Med 80:74–81

Allen JD, Esquela-Kerscher A (2013) Gongylonema pulchrum infection in a resident of Williamsburg, Virginia, verified by genetic analysis. Am J Trop Med Hyg 89:755–757

ANSES (2015) OPINION of the French Agency for Food, Environmental and Occupational Health & Safety on “the use of insects as food and feed and the review of scientific knowledge on the health risks related to the consumption of insects”. Request No. 2014-SA-0153. :1–38

Banjo D, Lawal O, Adeyemi I (2006) The microbial Fauna associated with the larvae of Oryctes Monocerus. J Appl Sci Res 2:837–843

Belluco S, Losasso C, Maggioletti M, Alonzi C, Ricci A, Paoletti MG (2015) Edible insects: a food security solution or a food safety concern? Anim Front 5:25–30

Belluco S, Losasso C, Maggioletti M, Alonzi C, Paoletti MG, Ricci A (2013) Edible insects in a food safety and nutritional perspective: a critical review. Compr Rev Food Sci Food Saf 12:296–313

Brinchmann BC, Bayat M, Brogger T, Muttuvelu DV, Tjonneland A, Sigsgaard T (2011) A possible role of chitin in the pathogenesis of asthma and allergy. Ann Agric Environ Med 18:7–12

Buckland-Nicks A, Hillier KN, Avery TS, O’Driscoll NJ (2014) Mercury bioaccumulation in dragonflies (Odonata: Anisoptera): examination of life stages and body regions. Environ Toxicol Chem 33:2047–2054

Chai JY, Shin EH, Lee SH, Rim HJ (2009) Foodborne intestinal flukes in Southeast Asia. Korean J Parasitol 47(Suppl):S69–102

Charlton AJ, Dickinson M, Wakefield ME, Fitches E, Kenis M, Han R, Zhu F, Kone N, Grant M, Devic E et al (2015) Exploring the chemical safety of fly larvae as a source of protein for animal feed. J Insects Food Feed 1:7–16

Constable A, Jonas D, Cockburn A, Davi A, Edwards G, Hepburn P, Herouet-Guicheney C, Knowles M, Moseley B, Oberdörfer R (2007) History of safe use as applied to the safety assessment of novel foods and foods derived from genetically modified organisms. Food Chem Toxicol 45:2513–2525

EFSA (2007) Opinion of the scientific scientific panel on biological hazards on microbiological criteria and targets based on risk analysis. EFSA J 462:1–29

EFSA (2008) Polycyclic aromatic hydrocarbons in food scientific opinion of the panel on contaminants in the food chain (question N° EFSA-Q-2007-136). EFSA J 724:1–114

EFSA (2013) Guidance on methodological principles and scientific methods to be taken into account when establishing reference points for action (RPAs) for non-allowed pharmacologically active substances present in food of animal origin. EFSA J 11:3195

EFSA (2014) A systematic procedure for the identification of emerging chemical risks in the food and feed chain. EFSA Support Publ 2014:EN-547:1–40

EFSA (2015) Risk profile related to production and consumption of insects as food and feed EFSA scientific committee. EFSA J 13(10):4257

EFSA (2016) Guidance on the preparation and presentation of the notification and application for authorisation of traditional foods from third countries in the context of regulation. EFSA 14:4590

Eilenberg J, Vlak JM, Nielsen-leroux C, Cappellozza S, Jensen AB (2015) Diseases in insects produced for food and feed. J Insects Food Feed 1:87–102

Engel K, Vogel RF, Knorr D, Habermeyer M, Kochte-Clemens B, Eisenbrand G (2011) The role of the concept of “history of safe use” in the safety assessment of novel foods and novel food ingredients. Opinion of the senate commission on food safety (SKLM) of the German Research Foundation (DFG). Mol Nutr Food Res 55:957–963

FAO/WHO (2010) Codex Alimentarius Commission: procedural manual 9th ed. Rome
FASFC Scientific Committee (2014) Common Advice SciCom. Food safety aspects of insects intended for human consumption. Sci Com dossier 2014/04; SHC dossier n° 9160
Gao Y, Chen J, Wang H, Liu C, Lv X, Li J, Guo B (2013) Enantiomerization and enantioselective bioaccumulation of benalaxyl in Tenebrio Molitor larvae from wheat bran. J Agric Food Chem 61:9045–9051
Gkogka E, Reij MW, Gorris LGM, Zwietering MH (2013) The application of the appropriate level of protection (ALOP) and food safety objective (FSO) concepts in food safety management, using listeria monocytogenes in deli meats as a case study. Food Control 29:382–393
Goodwin MA, Waltman WD (1996) Transmission of Eimeria, viruses, and bacteria to chicks: darkling beetles (Alphitobius Diaperinus) as vectors of pathogens. J Appl Poult Res 5:51–55
Green K, Broome L, Heinze D, Johnston S (2001) Long distance transport of arsenic by migrating Bogong moths from agricultural lowlands to mountain ecosystem. Vic Nat 118:112–116
Halloran A, Vantomme P, Hanboonsong Y, Ekesi S (2015) Regulating edible insects: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture. Food Secur 7:739–746
Han S-R, Lee B-S, Jung K-J, H-J Y, Yun E-Y, Hwang JS, Moon K-S (2016) Safety assessment of freeze-dried powdered Tenebrio Molitor larvae (yellow mealworm) as novel food source: evaluation of 90-day toxicity in Sprague-Dawley rats. Regul Toxicol Pharmacol 77:206–212
Han S-R, Yun E-Y, Kim J-Y, Hwang JS, Jeong EJ, Moon K-S (2014) Evaluation of genotoxicity and 28-day oral dose toxicity on freeze-dried powder of Tenebrio Molitor larvae (yellow mealworm). Toxicol Res 30:121
Handley MA, Hall C, Sanford E, Diaz E, Gonzalez-Mendez E, Drace K, Wilson R, Villalobos M, Croughan M (2007) Globalization, binational communities, and imported food risks: results of an outbreak investigation of lead poisoning in Monterey County, California. Am J Public Health 97:900–906
Hazeleger WC, Bolder NM, Beumer RR, Jacobs-Reitsma WF (2008) Darkling beetles (Alphitobius Diaperinus) and their larvae as potential vectors for the transfer of campylobacter jejuni and salmonella enterica serovar paratyphi B variant java between successive broiler flocks. Appl Environ Microbiol 74:6887–6891
Jeandron A, Rinaldi L, Abdyldaieva G, Usubalieva J, Steinmann P, Cringoli G, Utzinger J (2011) Human infections with Dicrocoelium Dendriticum in Kyrgyzstan: the tip of the iceberg? J Parasitol 97:1170–1172
Jongema Y (2015) World list of edible insects. Wageningen Univ. http://www.wageningenur.nl/upload_mm/7/4/1/ca8baa25-b035-4bd2-9fdc-a7df1405519a_WORLD LIST EDIBLE INSECTS 2015.pdf. Accessed 10 Nov 2015
Klunder HC, Wolkers-Rooijackers J, Korpela JM, Nout MJR (2012) Microbiological aspects of processing and storage of edible insects. Food Control 26:628–631
Kobayashi M, Sasaki T, Saito N, Tamura K, Suzuki K, Watanabe H, Agui N (1999) Houseflies: not simple mechanical vectors of enterohemorrhagic Escherichia Coli O157:H7. Am J Trop Med Hyg. 61:625–629
Latunde-Dada GO, Yang W, Vera Aviles M (2016) In vitro iron availability from insects and sirloin beef. J Agric Food Chem 64:8420–8424
Lv X, Liu C, Li Y, Gao Y, Wang H, Li J, Guo B (2014) Stereoselectivity in bioaccumulation and excretion of epoxiconazole by mealworm beetle (Tenebrio Molitor) larvae. Environ Saf 107:71–76
Memiş E, Türkez H, İncekara Ü, Banjo AD, Fasunwon BT, Toğar B (2013) In vitro biomonitoring of the genotoxic and oxidative potentials of two commonly eaten insects in southwestern Nigeria. Toxicol Ind Health 29:52–59
Mlcek J, Rop O, Borkovcova M, Bednarova M (2014) A comprehensive look at the possibilities of edible insects as food in Europe - a review. Polish J Food Nutr Sci 2014(64):147–157
Molavi GH, Massoud J, Gutierrez Y (2006) Human Gongylonema infection in Iran. J Helminthol 80:425–428

Musundire R, Osuga IM, Cheseto X, Irungu J, Torto B (2016) Aflatoxin contamination detected in nutrient and anti-oxidant rich edible stink bug stored in recycled grain containers. Dickens JC, editor. PLoS One 11:e0145914

Nelson W, Harris B (2006) Flies, fingers, fomites, and food. Campylobacteriosis in New Zealand—food-associated rather than food-borne. N Z Med J 119:U2128

Netherlands Food and Consumer Product safety authority (2014) Advisory report on the risks associated with the consumption of mass-reared insects

Noh J, Yun E, Park H, Jung K (2015) Subchronic oral dose toxicity of freeze-dried powder of Allomyrina dichotoma larvae. Toxicol Res 31(1):69–75

Pereira KS, Schmidt FL, Barbosa RL, Guaraldo AM, Franco RM, Dias VL, Passos LA (2010) Transmission of chagas disease (american trypanosomiasis) by food. Adv Food Nutr Res 59:63–85

Rumpold BA, Schlueter OK (2013) Potential and challenges of insects as an innovative source for food and feed production. Innov Food Sci Emerg Technol 17:1–11

Srinroch C, Srisomsap C, Chokchaichamnankit D, Punyarit P, Phiriyangkul P (2015) Identification of novel allergen in edible insect, Gryllus Bimaculatus and its cross-reactivity with macrobrachium spp. allergens. Food Chem 184:160–166

Stoops J, Crauwels S, Waud M, Claes J, Lievens B, Van Campenhout L (2016) Microbial community assessment of mealworm larvae (Tenebrio Molitor) and grasshoppers (Locusta migratoria migratorioides) sold for human consumption. Food Microbiol 53:122–127

Templeton JM, De Jong AJ, Blackall PJ, Miflin JK (2006) Survival of campylobacter spp. in darkling beetles (Alphitobius Diaperinus) and their larvae in Australia. Appl Environ Microbiol 72:7909–7911

Trotta Barroso Ferreira R, Melandre AM, Cabral ML, Branquinho MR, Cardarelli-leite P (2016) Extraction of Trypanosoma cruzi DNA from food : a contribution to the elucidation of acute Chagas disease outbreaks. Rev Soc Bras Med Trop 49:190–195

van Broekhoven S, Gutierrez JM, de Rijk TC, de Nijs WCM, van Loon JJA (2014) Risk of mycotoxin contamination of edible mealworms. In: World mycotoxin forum 2014. Vienna

van den Berg M, Denison MS, Birnbaum LS, DeVito MJ, Fiedler H, Falandysz J, Rose M, Schrenk D, Safe S, Tohyama C et al (2013) Polybrominated Dibenzo-p-dioxins, dibenzofurans, and biphenyls: inclusion in the toxicity equivalency factor concept for dioxin-like compounds. Toxicol Sci 133:197–208. [Accessed 2017 Mar 14]. https://academic.oup.com/toxsci/article-lookup/doi/10.1093/toxsci/kft070

van der Spiegel M, Noordam MY, van der Fels-Klerx HJ (2013) Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. Compr Rev Food Sci Food Saf 12:662–678

Verhoeckx KCM, van Broekhoven S, den Hartog-Jager CF, Gaspari M, de Jong GAH, Wichers HJ, van Hoffen E, Houben GF, Knulst AC (2014) House dust mite (der p 10) and crustacean allergic patients may react to food containing yellow mealworm proteins. Food Chem Toxicol 65:364–373

Vijver M, Jager T, Posthuma L, Peijnenburg W (2003) Metal uptake from soils and soil–sediment mixtures by larvae of Tenebrio Molitor (L.) (Coleoptera). Ecotoxicol Environ Saf 54:277–289

Wales AD, Carrique-Mas JJ, Rankin M, Bell B, Thind BB, Davies RH (2010) Review of the carriage of zoonotic bacteria by arthropods, with special reference to salmonella in mites, flies and litter beetles. Zoonoses Public Health 57:299–314

Zhuang P, Zou H, Shu W (2009) Biotransfer of heavy metals along a soil-plant-insect-chicken food chain: field study. J Environ Sci (China) 21:849–853

Part IV
Gastronomy

A New World of Ingredients: Aspiring Chefs' Opinions on Insects in Gastronomy

Afton Halloran and Roberto Flore

Abstract Insects have been absent from European diets with only few regional exceptions, making them an uncommon ingredient in the kitchens of fine dining establishments. This chapter investigates whether a piece the puzzle of understanding the temporality or permanence of edible insects in modern European diets lies in the willingness of chefs to use them as ingredients? Understanding the opinions of aspiring chefs can help us map the future use and diffusion of insects in high-gastronomy helps to speculate the pervasiveness of insects in European diets. We assess the opinions of 68 aspiring young chefs studying at the Basque Culinary Centre towards the use of insects in gastronomy. We found that there is a general willingness to experiment with different insect species in the kitchen if properly trained and educated how to do so. However, there are still some practical and cultural barriers that must be overcome to promote widespread acceptance.

1 Introduction

To some, insects represent a new world of ingredients; to others, they are a common or seasonal element of traditional diets. In Europe, insects have been absent from European diets with only few regional exceptions (Belluco et al. 2017), making them an uncommon ingredient in the kitchens of fine dining establishments. Considering insects as avant-garde demonstrates the new gastronomic value that has been placed on these diverse ingredients. However, insects are not new ingredients. Rather, they are ingredients that have been used for millennia and have been a robust part of traditional food culture in many world regions (Halloran et al. 2015; Evans et al. 2017). However, it is their absence from dominant European

A. Halloran (✉)
Department of Nutrition, Exercise and Sports, University of Copenhagen, Frederiksberg C, Denmark

R. Flore
Nordic Food Lab, Department of Food Science, University of Copenhagen, Frederiksberg C, Denmark

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_8

cuisines that has contributed to the fact that insects are often cited as 'new' and innovative ingredients in recent years. In the past, Western gastronomic cultures, and French cuisine in particular, were often viewed as superior. As such, what we eat and have not eaten in Europe as well as other regions of the world, as well as what we consider as avant-garde, is often a result of historical battles for cultural superiority (Laudan 2015).

In 1921, Dr. Joseph Bequaert of the American Museum of Natural History wrote that "…to many it is surprising and can be attributed only to prejudice, that civilized man of today shows such a decided aversion to including any six-legged creatures in his diet… what we eat and what we do not eat is, after all, a matter of custom and fashion (rather) than anything else…" (Bequaert 1921). Now, more than ever, these fashions, or trends, are increasingly influenced by the gastronomic community. Popular chefs act as influencers and thought-leaders, communicating their ideas through all forms of mass-media, generating excitement for certain kinds of products and acting as intermediaries between food cultures (Lane and Fisher 2015; Piper 2015).

While numerous studies have analysed the perceptions and reactions of consumers to edible insect and insect products, as well as the readiness of consumers in Europe (see, for example, Caparros Megido et al. 2014; Verbeke 2015; Tan et al. 2016; Verneau et al. 2016), limited information exists on the perception of using insects from the point of view of chefs. Neophobia and disgust aside, Halloran et al. (2015) noted that the widespread use of insects was limited by a general lack of knowledge of the complexity and variation of these ingredients. However, this can be changed. Tan et al. (2015) found that cultural exposure resulted in greater knowledge of the preparation of insects whereas those with little exposure were unaware of the preparations and sensory properties of insects. In fact, food and taste education have been tactics to improve awareness of different edible insect species in North America and Europe. According to Slow Food International "by understanding where our food comes from, how it was produced and by whom, adults and children can learn how to combine pleasure and responsibility in daily choices and appreciate the cultural and social importance of food" (Slow Food International 2017).

Outside of Europe, insects are a far more common part of diets, especially in the tropics and sub-tropics. In a country with 545 edible species (Ramos-Elorduy 2008), it is not surprising that fine dining restaurants in Mexico have exhibited some of the most prevalent and refined uses of insects. For example, on his May 2016 menu Quintonil's Jorge Vallejo served charred avocado tartare with escamoles, which played on the subtle flavour of the *escomoles* (ant larvae) and the smooth, nutty avocado. On the seven course tasting menu Pujol chef Enrico Oliviera created one dish consisting of baby maize with powdered chicatana ant, coffee, costeño chile mayonnaise and another made of egg *infladita* with chapulin sauce, beans and avocado leaves (May 2016 menu). In 2013 in Brazil, another country with high insect biodiversity chef Alex Atala served a pineapple dessert with a leaf-cutter ant to highlight indigenous and Amazonian produce at his restaurant D.O.M. in São Paolo.

In Europe, Restaurant noma has also experimented with different insect species since 2012 and has created such dishes as live ants (*Formica rufa*) with crème-fraîche for a pop-up at Claridges Hotel in London and black ants (*Lasius fuliginosus*) on botan prawns for the noma pop-up in Tokyo in 2016. Other fine dining restaurants in Copenhagen have also been found to use *Formica rufa* and *Lasius fuliginosus*. In 2017, at a pop-up in Mexico, noma served piñuela with red maguey caterpillars, a tostada with escamoles and a dessert made with avocado and fresh yogurt sorbet with sour ant paste served in a grill avocado.

Despite these examples, insects are still an uncommon ingredient in the kitchens of fine dining establishments. Could a piece of the puzzle of understanding the temporality or permanence of edible insects in European diets lie in the willingness of chefs to use them as ingredients? As such, we argue that chefs are an important instigator of the trickledown effect that would bring insects and insect products into European households. Understanding the opinions of aspiring chefs can help us speculate the future use and diffusion of insects in high-gastronomy and helps to speculate the pervasiveness of insects in European diets. This preliminary study provides an assessment of the opinions of aspiring young chefs studying at the Basque Culinary Centre towards the use of insects in gastronomy.

2 Methods

On December 16th, 2015 and again on September 21st, 2016, a 4 h in-depth lecture on the topic of insects in gastronomy was held at the Basque Culinary Centre in Donostia (San Sebastián), Basque Country (Fig. 1). The Basque Culinary Centre (BCC) is a culinary foundation created in 2009 by Mondragon University and a group of prominent Basque chefs. The BCC serves as a training, research and

Fig. 1 MSc students who attended the lecture on September 21st, 2016 (Photo: Afton Halloran)

Fig. 2 MSc students at the Basque Culinary Centre tasting bee larvae served on a tostada on September 21st, 2016 (Photo: Afton Halloran)

innovation centre and aims at developing the culinary sector. Students from MSc in Cooking, Technique, Innovation and Product and MSc in Avant-Garde and Innovation in Gastronomy attended the lecture (Fig. 1). A questionnaire requesting both qualitative and quantitative responses was distributed to the students at the beginning of the lecture. A total of 68 students responded: 40 on December 16th and 28th on September 21st, 2017. The questionnaires were collected at the end of the lecture.

Towards the end of the lecture, the students were given samples of bee larvae prepared in different ways (frozen, sautéed and on top of a tostada, a fried tortilla[1] made from nixtamalized Øland wheat (Fig. 2)) in order to see the difference in the taste of insects subject to different preparations. Samples of Anty Gin (a gin made with distilled *Formica rufa* co-created by the Nordic Food Lab and Cambridge Distillery) and grasshopper garum were also given to the students to sample.

3 Results

The data combines the questionnaire results from 2015 and 2016. Sixty percent of the respondents were male and 40% were female. The average age of the respondents was 24. The respondents represented 13 different nationalities with the vast majority coming (73.5%) from various regions of Spain.

[1] Tostadas are most commonly made with tortillas from nixtamalized maize. The recipe that was prepared by chapter author, Roberto Flore, using Nordic ingredients, hence the nixtamalized Ølands wheat instead of the maize.

Prior to the presentation, 76% of the respondents had consumed one or more insect species. Of the nationalities represented, only 12% of the respondents said that insects were a part of regional cuisine of their country of origin, all of whom were from Latin America.

3.1 The Most Convincing Argument for Insects in Modern Gastronomy

Thirty-one percent of the students recognised identity, cultural heritage and tradition as the most convincing argument for insects in modern gastronomy. Twenty percent and 14% recognised environmental sustainability and taste/palatability as the most convincing arguments, respectively. This was followed by 12% for novelty, 11% for health/nutrition, 6% for top chefs using insects as an ingredient in their restaurants and 6% for the 'other' category.

3.2 Barriers to the Use of Barriers in Modern Gastronomy

Of the barriers to the use of insects in modern gastronomy, 47% noted that disgust was the most significant. Lack of knowledge on how to use and prepare insects was rated as the second largest barrier (21%). This was followed by inaccessibility to products (15%), prohibitive food safety regulations (10%) and association with poverty (3%). High cost and 'other' were seen as the least significant barriers (2%, respectively).

Of those who saw disgust as the most significant barrier, education was recognised as an important means of overcoming it. According to a Colombian student (25 years old):

> I think that the disgust barrier is enormous because insects are associated with dirt, soil, ground, garbage, etc. The only way to overcome this is providing information on farming to regular consumers so they can understand that insects are like any other protein.

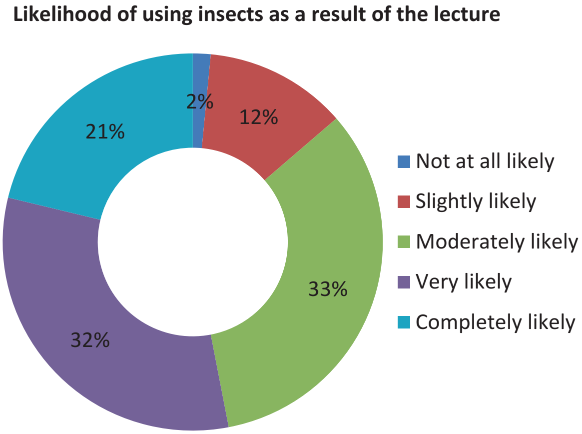
Further, creating delicious dishes was seen as another way to overcome the barrier of disgust, although there was discrepancy in how to actually carry this out. A Spanish student (29 years) noted that:

> In my opinion, this barrier can be overcome by mixing with other ingredients to make delicious dishes.

The lack of knowledge on how to use and prepare insects could be overcome "by watching the countries that always have used insects in gastronomy" (Venezuelan student, 27 years old) or through informing consumers about the qualities of the products:

> Nutrition may be the key to open the world of insect consumption. I mean, once the people know the benefits of the consumption, they will be more likely to accept the flavours and find out more things – Chinese student, 27 years old

Fig. 3 The likelihood of using insects in creating a new dish as a result of the lecture



3.3 Likelihood of Using Insects in a Gastronomic Context

As a result of the four hour lecture on edible insects in a gastronomic context, the majority of the students showed a positive response to using insects in future dishes (Fig. 3). Those coming from countries where insects were a traditional part of regional cuisine were on average very likely to use insects in creating a new dish:

> It’s used in my culture and also I think that it would be well accepted by consumers. Also it's important to spread the word about the good flavours and attributes that insects have. – Mexican student, 27 years old

> As a cook, I definitely look at the world as if almost everything is edible, and since I was a little girl my dad gave me ants from Colombia (*culonas*). I would probably try to represent that on a dish. Also try new uses of the ant because traditionally they are fried. I would like to take the whole flavour of it and use it for something else. – Columbian student, 25 years old

On the other hand, those who did not come from countries where insects were a part of regional cuisine were slightly less likely to use insects in creating a new dish in the future:

> I think that it is not profitable in a restaurant in Spain – Spanish student, 29 years old

> It isn’t a product that I feel comfortable with using – Spanish student, 26 years old

Others saw insects as a new ingredient that could be used to enhance and develop the flavour of dishes but may encounter some difficulties in Spanish gastronomy:

> You can use a *formica rufa* instead of oxalis. If you can use a wild plant to create a plate, why can't you use an insect with the same flavour to create the same dish? Insects are a new world of ingredients, but it’s not easy to introduce in the Spanish gastronomy. – Spanish student, 27 years old

> [You should only use them] if it makes sense in the dish. But, you should not just add insects because they are cool or new and different. – Spanish student, 25 years old

> [Insects] give a lot of new possibilities and new flavours that can be introduced in different ways, different textures. – Spanish student, 21 years old

3.4 Most Convincing Argument for Consuming Insects

The students recognised nutritional, environmental and taste/deliciousness arguments as the most important arguments for the consumption of edible insects (31%, 29% and 29%, respectively) (Fig. 3). Three students explained why:

> I think that the nutritional values of the insects will have a potential future in the food industry. – Chinese student, 27 years old

> Nowadays, as population grows, we have no other choice but to look for alternatives in the environment. – Spanish student, 20 years old

> I think [taste] could be the most effective way/argument to make people eat insects because actually the taste of food is the most important reason why we eat food, for enjoyment and pleasure. We can eat something tasty that doesn't make our health get better, but people won't eat something because it is good for environment but has no taste. – Spanish student, 21 years old

Nine percent ranked the economic argument (e.g. can provide employment and stimulate rural economy) as most important and 1% found that no argument was convincing enough and 1% cited 'other' arguments.

4 Discussion

Lectures and workshops such as the one featured in this chapter have a clear importance in disseminating information about the diversity of taste across insect species. In Europe, the dissemination of techniques and knowledge of different edible insect species and the food cultures that they are a part of is an important part of enabling chefs to experiment with these ingredients. The Basque Culinary Centre has displayed interest in educating their students on these relatively forgotten ingredients. In 2015, Le Cordon Bleu in Bangkok hosted a free public workshop entitled 'Insects in a Gastronomic Context' where the culinary part of the workshop was led by chapter author Roberto Flore and the academic part of the workshop was led by chapter author Afton Halloran. Fifty-one people attended (for further information see Halloran et al. 2015). Le Cordon Bleu in Bangkok has since hosted other events featuring insects.

Still, disgust remains a major barrier to the widespread acceptance of edible insects. As food preferences are formed early in life (Skinner et al. 2002; De Cosmi et al. 2017), some scholars and practitioners have advocated introducing insects to children. Other avenues to normalising insects in modern gastronomy have also been realised in recent years. For example, the Nordic Food Lab released a book entitled *On eating insects: essays, stories and recipes* in May 2017. This book is the first of its kind to holistically address issues of taste, cooking techniques and culture surrounding the use of edible insects. At the end of the book there are 35 recipes that are available together with a detailed list of tasting notes for 37 insect species. The 2016 documentary, *Bugs*, by Andreas Johnsen follows researchers from the Nordic Food Lab (including chapter author, Roberto Flore) in pursuit of discovering how edible insects are used in different cultures. Another example comes from Spain where, in June 2017, Master Chef Spain aired the first ever episode dedicated to edible insects, where chapter author Roberto Flore presented four dishes and different ways to prepare insects for the remaining four contestants as well as three celebrity judges. The program was viewed on the day it was first aired by an estimated 3.6 million people.

Identity, culture and traditions related to food provide a justification and strong argument for the selection of certain ingredients in fine dining establishments (Vackimes 2013; Bech-Larsen et al. 2016; Gyimóthy 2017). However, we argue that tradition is not a static but rather dynamic, constantly challenged and influenced process. As such, new culinary traditions can be created as we have already seen in modern gastronomy. The increased involvement of diverse stakeholders in developing modern interpretations of local cuisine, like, for example, the New Nordic Cuisine, are driving chefs to explore their own territories and valorise ingredients which may have previously been absent from traditional cuisine, or forgotten during the modernization of a regional cuisine.

5 Conclusion

This chapter has analysed aspiring chefs' opinions on the use of edible insect species in a gastronomic context. In doing so, we have explored opinions concerning the most convincing arguments for using insects in modern gastronomy; the most significant barriers to the use of insects in modern gastronomy; the likelihood of using insects in creating a new dish as a result of the lecture; and the most convincing argument for eating insects. We found that there is a general willingness of future chefs (chefs-to-be) to experiment with different insect species in the kitchen if properly trained and educated how to do so.

Despite the use of insects by a handful of elite chefs, insects are still far from being recognised as a common ingredient in fine-dining establishments. Removing the disgust factor by increasing the appeal of insects and educating chefs about the applications of insects in a gastronomic context are two of the ways in which insects could become more common place not only in fine dining, but also in casual dining.

References

Bech-Larsen T, Mørk T, Kolle S (2016) New Nordic cuisine: is there another back to the future? – an informed viewpoint on NNC value drivers and market scenarios. Trends Food Sci Technol 50:249–253. https://doi.org/10.1016/j.tifs.2016.01.020

Belluco S, Halloran A, Ricci A (2017) New protein sources and food legislation: the case of edible insects and EU law. Food Sec 9(4):803–814

Bequaert J (1921) Insects as food. How they have augmented the food supply of mankind in early and recent years. J Nat Hist 21:191–200

Caparros Megido R, Sablon L, Geuens M et al (2014) Edible insects acceptance by Belgian consumers: promising attitude for entomophagy development. J Sens Stud 29:14–20. https://doi.org/10.1111/joss.12077

De Cosmi V, Scaglioni S, Agostoni C (2017) Early taste experiences and later food choices. Forum Nutr 9:107. https://doi.org/10.3390/nu9020107

Evans J, Flore R, Frøst MB (2017) On eating insects: essays, stories and recipes, 1 st edn. Phaidon Press, London/New York

Gyimóthy S (2017) The reinvention of terroir in Danish food place promotion. Eur Plan Stud 25:1200–1216. https://doi.org/10.1080/09654313.2017.1281229

Halloran A, Flore R, Mercier C (2015) Notes from the "insects in a gastronomic context" workshop in Bangkok, Thailand. J Insects Food Feed:1–4. https://doi.org/10.3920/JIFF2015.0070

Lane SR, Fisher SM (2015) The influence of celebrity chefs on a student population. Br Food J 117:614–628. https://doi.org/10.1108/BFJ-09-2013-0253

Laudan R (2015) Cuisine and empire: cooking in world history., Reprint edition. University of California Press, Berkerley

Piper N (2015) Jamie Oliver and cultural intermediation. Food Cult Soc 18:245–264. https://doi.org/10.2752/175174415X14180391604288

Ramos-Elorduy J (2008) Energy supplied by edible insects from Mexico and their nutritional and ecological importance. Ecol Food Nutr 47:280–297. https://doi.org/10.1080/03670240701805074

Skinner JD, Carruth BR, Bounds W, Ziegler PJ (2002) Children's food preferences: a longitudinal analysis. J Am Diet Assoc 102:1638–1647. https://doi.org/10.1016/S0002-8223(02)90349-4

Slow Food International (2017) Food and taste education – what we do. In: Slow food international. https://www.slowfood.com/what-we-do/food-and-taste-education/. Accessed 14 Jun 2017

Tan HSG, Fischer ARH, Tinchan P et al (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89. https://doi.org/10.1016/j.foodqual.2015.01.013

Tan HSG, Fischer ARH, van Trijp HCM, Stieger M (2016) Tasty but nasty? Exploring the role of sensory-liking and food appropriateness in the willingness to eat unusual novel foods like insects. Food Qual Prefer 48, Part A:293–302. https://doi.org/10.1016/j.foodqual.2015.11.001

Vackimes SC (2013) Catalan high-end restaurants and national "heritage.". Catalan J Commun Cult Stud 5:271–284. https://doi.org/10.1386/cjcs.5.2.271_1

Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a western society. Food Qual Pref 39:147–155. https://doi.org/10.1016/j.foodqual.2014.07.008

Verneau F, La Barbera F, Kolle S et al (2016) The effect of communication and implicit associations on consuming insects: an experiment in Denmark and Italy. Appetite. https://doi.org/10.1016/j.appet.2016.02.006

Casu Marzu: A Gastronomic Genealogy

Luca Manunza

L'esperienza quotidiana della nascita dei vermi
dal formaggio putrefatto serviva a
Menocchio per spiegare la nascita di esseri viventi
- i primi, i piú perfetti, gli angeli
- dal caos, dalla materia «grossa et indigesta»,
senza ricorrere all'intervento di Dio

Menocchio employed the everyday occurrence
of worms being born in rotten cheese
to explain the birth of living beings
- the first, absolute perfection, were angels
- from a chaotic 'large and undigested' mass,
without relying on God's intervention.

Carlo Ginzburg (1999), The cheese and the worms. The cosmos
of a sixteenth-century miller.

Abstract *A dog's life,* a shockumentary by directors Jacopetti and Prosperi (1962), for the very first time depicts culinary customs from some ten countries around the world. The authors employ a fast-paced sequence of *near and far-flung* cultures to ask viewers to what extent the cuisine of each country can embody differences, disrupt modernity, spark indignation, or simply create puzzlement and curiosity.

L. Manunza (✉)
Capitol, Università degli Studi Suor Orsola Benincasa di Napoli, (URIT), Naples, NA, Italy

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_9

1 Introduction

A dog's life is a tangible analysis of *eating taboos* which reflects on diets and using insects in the kitchen (a debate which, although myopic[1] in scope, has recently resurged in the West).

The documentary also visits one of the most important restaurants in New York, the Colony. It is the Sixties and the camera sweeps over small, packaged exotic delicacies and the upper echelon of society dining while, over the typical background buzz of a restaurant, the voiceover says:

> *In New York, for the person who likes to spend, there's a famous restaurant, one of the most sophisticated and expensive in the world. While the middle-class American has to content himself with the daily steak, here, the richer American con gorge himself heartily on the following delicacies: fried ants, stuffed beetles, butterfly eggs, worms au gratin, rattlesnake, muskrat, and so forth.*

1.1 Western Society's Reactions to Eating Insects

A dog's life caused an angry outburst in Western society, especially in Italy, the directors' country. The outburst was caused by one fact: the documentary showed how unthinkable and uncommon dishes in our diet were being eaten in the West. These dishes, according to a commonly accepted belief, could, after all, only be cooked and eaten in underdeveloped regions of the planet.

Italy, and parts of the Western world, was getting back on its feet following World War II. It was a time of modernity, a useful watershed moment between *us and the other* (Clifford and Marcus 1986; Remotti 2011), a time where even gastronomy and the *Mediterranean diet* (Niola 2015) contributed to Italy's identity by means of new inventions as well as by removing some historical and cultural elements. Eating insects was unthinkable. In the past and, to a certain extent, even today, it was unacceptable for a modern society to eat animals or insects from *other cultures and diets,* or use them as ingredients in recipes.

This paper focuses on that debate. It aims to reflect, in part, on why *Western societies are against using insects in their everyday diets and if there are any answers to counteract this phenomenon.*

To illustrate this case, a paradigmatic food was chosen: ***Casu Marzu***, a Sardinian diary delicacy. It visually reminds us how eating and using insects as a main ingredient in a recipe is part of *our gastronomic* tradition and, therefore, its rejection can be linked to legislative prescriptions as well as *gastronomic racism.*[2]

---

[1] This short-sightedness is due to the numerous hard-lining practices which interpret the sales of insects as a cultural and economic threat.

[2] Gastronomic racism is a provocation which aims to highlight the shapes rejection and discrimination towards the 'other' can take by employing a process of crystallisation and rewriting the history of gastronomic cultures.

In Sardinian, ***Casu Marzu*** literally means 'rotten cheese'. This cheese is one of the 183 traditional food products recognised by the Italian Ministry for Agricultural, Food, and Forestry Policies (MIPAAF). The cheese is produced by processing the sheep's raw milk (at 35°), which is then curdled with calf rennet. Once it has been given its shape, it is placed in brine for approximately 24 h. After indicatively 15 days, the cheese is attacked by 'cheese flies', the *Piophilia casei*, which lay their eggs inside the cheese. The larvae feed off the cheese itself for around 2 weeks. The enzymes produced by the larvae favour the cheese's fermentation and give it its final shape. The resulting cheese contains hundreds of tiny worms delivering a unique flavour to the food product. By eating it, we are also eating small worms mixed with a creamy cheese. This is clear proof that eating insects is not a new phenomenon in our society.

For decades, ***Casu Marzu*** has been regulated by a law which bans its sale. It was passed in 1962 (Law No. 238) and which, strangely enough, coincides with the release of *A dog's life*. The law does not consider Italy's eating history, unable to balance food safety and the enhancement of traditional products, as it prohibits the sale of ***Casu Marzu*** and all products *beleaguered by parasites.*

This law believes it is not possible for a healthy product to contain insects and, thus, it cannot be sold. It believes the product is produced using non-industrial fermentation processes or, even worse, that the product is made by purposely introducing larvae in it. Niola (2015) claims it is a law which threatens to promote orthorexia, an *eating disorder* characterised by an obsession with consuming healthy food which, in the time being, has become one of the most widespread eating disorders in the West.

Just like honey, which is produced by a bee's digestive system, ***su Casu Fràzigu's***[3] peculiarity is based on what the small larvae eat while nesting in the cheese.

An insect-based diet is not limited to the island but can be found across Europe, as proven by cheese similar to ***Casu Marzu*** in other Mediterranean countries: from Egypt to Greece as well as in Italy.[4]

Despite the legislative imposition, according to numerous experts and researchers, ***su Casu Marzu*** is a safe cheese from a microbial perspective: indeed, according to Professor Deiana (2016), Professor of Food Microbiology, the cheese features a concentrate of essential vitamins and amino acids. This may explain why its supporters have been talking for years of its virile-enhancing properties (Zerda and Mainarchi 1971).

Associating insects and diets is often trivialised as a hallmark of an underdeveloped country or society, as proven by many claims and word of mouth alike.

---

[3] Casu Marzu has a regional identity, meaning it adopts different names based on the province where it is produced: *casu mùchidu*, *casu modde*, *casu giampagadu*, *casu fatitu*, *casu becciu*, *casu 'attu*, *casu cundítu*.

[4] Italian examples of these cheeses can be found in the Friuli (*Saltarello*) and Abruzzo (*Marcetto*) regions. The *Gorgonzola delle Grotte*, *Begiunn*, *Formaggio di Fossa* and many others exist. The *Casgiu Merzu*, obtained using goat sheep, similarly to the Sardinian sheep, is found in Corsica. There is also a similar cheese in Croatia, as well as the German *Milbenkäse* or the French *Mimolette*.

Casu Marzu, even in Sardinia, is often judged as a product that is incapable of *delivering added value to the island's image of producing good wine and food.* Thus, Sardinia's image comes into question. Does associating Sardinia with ***Casu Marzu*** mean promoting an idea of an underdeveloped island population as claimed by Lombroso (1876)? Does it mean risking the loss of a recognised tradition in nearly all the world, namely that of an island known for its good wine, myrtle, and ravioli, expertly shaped into an ear of corn? It goes beyond that (Manunza 2016).

What is at stake here, to use Goffman's expression (1969), is succumbing to *gastronomic* racism at our own tables. This could lead us to distance ourselves from traditional experiences, an attitude which legitimises the misunderstanding between what folklore and tradition are: this misinterpretation is devastating for every culture and society (Cardini 2016).

Opposite values, like *cuisine and gastronomy,* cannot be objectively founded from an anthropological perspective. Cuisine is the number of ways and techniques society uses to transform nature into food products. Gastronomy is the art of preparing or cooking food well (Niola 2009).

The accepted opinion is that gastronomy is only present in complex, rich, and modern cuisines and they do not include insects. However, the poorest among the agricultural methods to prepare food were based on the *aesthetics and physiology of flavour,* which were not inferior to those found in 'better' cuisines. Therefore, each culture projects its particular culinary categories on the others, thus overlapping, and adopting an *ethnocentric* view towards everyone who eats differently (Douglas 1985; Goody 1985). This is what partially occurred to ***Casu Marzu*** from a micro perspective and to eating insects in the West from a macro perspective.

1.1.1 Su Casu Marzu: A Gastronomic and Cultural Product

For some people, it is important that their diversity not be stigmatised. Therefore, every cuisine has its gastronomy: outstanding principles that constitute the *aesthetic sublimation of its food grammar,* as said by Niola (2009). Thus, preparing a cheese using natural procedures, created by the human experience, represents a gastronomic and cultural passage that must be preserved; it teaches us how insects can be excellent ingredients and not only mere representatives of *eastern traditions and diversity,* as postulated by Said (1978).

Casu Marzu completely changes our perception of insects. As a protein source and unique, as well as complete, food product to an *all-round gastronomic product* based on dairy traditions employing different ingredients, the knowledge of the island's microclimate as well as overlapping traditions, history, and the knowledge of the territory.

The resistance to using insects in cooking can be associated with using a *genealogy of western diets* and their perception of 'progress'. While it may be true that in many cultures there is a ban on eating something simply based on what it is, the

Fig. 1 Screenshot e-commerce e-bay. http://www.ebay.it/itm/Casu-Marzu-Formaggio-con-i-vermi-Crema-Delizia-Sarda-/252960802191?hash=item3ae5a3858f:g:tmwAAOSwB09YMzFb

criteria used to assess edibility is based on categories: near-far, similar-dissimilar, pure-impure, human-animal, man-woman.

This is where *eating taboos* in cultures come from: pork for Jews and Muslims, dogs, horses for Anglophone and German populations, or insects, which are considered unpalatable by the West during this postmodern period.

The debate on using insects in diets in the Old Continent has become more topical and global than ever, as proven by the presence of the Sardinian cheese, a Protected Designation of Origin product (PDO), on some of the most used e-commerce sites in the world (Fig. 1).

A fact limited to theories and musings which too often aim to create distance and make us forget that eating insects is part of our culture (Mellini 1956).

The speech by Foucault (1972) on the acceptance of insects as part of our diet does not consider history, but is based exclusively on the *a priori rejection* of eating insects and a distorted view of gastronomy.

Like with any other prescription, even *eating taboos* have a deep effect on our societies, becoming proper *dispositifs* (Deleuze 2007). The question is easy: how do we reject insects in our diets despite their widespread and proven presence? Do any tools and answers that allow us to reclaim and preserve the gastronomic culture exist, thus destroying this imposed eating etiquette?

The story about *su Casu Marzu* is an enlightened answer. Indeed, since 2005, Sardinia has had a *Committee to Promote Casu Marzu(PDO)*.[5] The committee carried out all the required exams to produce the cheese. It also successfully requested that the larvae used in the production process of ***Casu Marzu*** be conceived in a controlled environment which complies with the hygienic and sanitary regulations of a regular laboratory (Mazzette et al. 2010).

The abovementioned process circumvents the pertinent legislation while at the same time guaranteeing the sanitary requirements demanded to produce a food product without any ensuing health risks for people. The committee's proposal resulted in the drafting of specifications shared among sheep farmers and sanitary institutions (which is why the Committee has a strong collaboration with the Faculty of Veterinary Medicine of the University of Sassari). Therefore, it would be ideal if dairy producers were to use colonies of *Piophilia Casei* produced in a controlled environment to manage their colonisation and avoid relying on accidental infestations.

Besides the myth (Lévi-Strauss 1969), the Sardinian Casu Marzu represents the umpteenth example of the intellectual liveliness of a people that transformed what looked like a mistake in the beginning, a potential disaster, into a gastronomic success.

A series of involuntary events, from the initial preparation in facilities which were far from aseptic, to the conservation and short maturing timeframe in non-conventional locations, organised in the correct succession, produced cheese colonised by *Piophilia casei* larvae – fought by dairy farms the world over – that transformed a sheep's cheese into a PDO of excellence.

What is the future of this cheese? One possible answer would be to contact the Committee which determines the production and sales regulations of 'novel food'.[6] Adding Casu Marzu to the *Novel Food Catalogue* would be an important acknowledgment as well as being something owed to its producers and consumers.

---

[5] The Committee is chaired by Mario Demontis, Councillor for Agriculture of the Municipality of Ossi. Antonello Salis, an entrepreneur from Ploaghe President of Cna Sardegna, Mario Loriga (Mountain Community of Osilo), Nico Masia (former councillor for agricultural of the municipality of Florinas) and Antonio Meloni (President of the animal breeder cooperative of Villanova Monteleone) are also members of the Committee.

[6] Novel Food (new food or new food ingredients) fall under the European Union's legislation, specifically under Regulation (EC) 258/97. Novel food are all products and food substances where a 'significative' consumption cannot be proven on or after 15 May 1997 within the European Union (UE), date when the Regulation came into power. Casu Marzu perfectly meets the European directive on access criteria for being considered a 'novel food'. '*Novel food will only be approved for use in the EU if they do not present a risk to public health, are not nutritionally disadvantageous when replacing a similar food and are not misleading to the consumer. They must undergo a scientific assessment prior to authorisation to ensure their safety. The authorisation sets out, as appropriate, the conditions for their use, their designation as a food/food ingredient and labelling requirements*', see European Commission website: http://ec.europa.eu/food/safety/novel_food/authorisations_en

To do so, one would have to see the cheese as the container of larvae which need that type of product to exist. A shift of perspective which would benefit many people and change the current challenge to one which demands us to reinterpret traditions.

References

Cardini F (2016) I giorni del sacro: I riti e le feste del calendario dall'antichità a oggi. UTET, Novara

Clifford J, Marcus GE (1986) Writing culture: the poetics and politics of ethnography. University of California Press, Berkeley

Deiana P (2016) Tutti pazzi per il formaggio illegale, interview at the italian channel La7, Rome, 2016. https://www.youtube.com/watch?v=zgyipBmDqhU

Deleuze G (2007) Che cosa è un dispositivo? Coronopio, Napoli

Douglas M (1985) Food as a means of communication, in Antropologia e simbolismo. Il Mulino, Bologna

Foucault M (1972) The archaeology of knowledge and the discourse on language. Tavistock Publications, Ltd, London

Ginzburg C (1999) The cheese and the worms. The cosmos of a sixteenth-century miller. John Hopkins University Press, Baltimore

Goffman E (1969) The presentation of self in everyday life. Random House, New York

Goody J (1985) Cooking, cuisine, class. A study in comparative sociology. Cambridge University Press, Cambridge, MA

Jacopetti G, Prosperi F (1962) A Dog's Life, Rizzoli, Italia

Lévi-Strauss C (1969) The raw and the cooked. Harper and Row, Publishers, Inc, New York

Lombroso C (1876) L'uomo delinquente. Hoepli, Milano

Manunza L (2016) Il lavoro stagionale nel settore turistico in Sardegna. Cartografie Sociali n.1. Mimesis, Milano

Mazzette R, Colleo MM, Riu G, Piras G, Piras F, Addis M, Pes M, Pirisi A, Meloni D, Mureddu A, Spada S, Fiori M, Coinu M, Lentini A (2010) Production under controlled conditions of "casu marzu" cheese: effect of the *Piophila casei* colonization on microbial and chemical composition of the cheeses. Italian J Food Safety Rivista dell'Associazione Italiana dei Veterinari Igienisti 7:45–54

Mellini E (1956) Insetti e Gastronomia (alle massaie d'Italia) NATURA E MONTAGNA. Anno III, n.4 82-87, Bologna

Niola M (2009) Si fa presto a dire cotto: un antropologo in cucina. Il Mulino, Bologna

Niola M (2015) Homo dieteticus. Viaggio nelle tribù alimentari. Il Mulino, Bologna

Remotti F (2011) Cultura. Dalla complessità all'impoverimento. Laterza, Bari

Said EW (1978) Orientalism. Random House, New York

Zerda N, Mainarchi G (1971) Guida all'Italia amorosa galante erotica libertina. Sugar Editore, Milano

Edible Insects Uses in South Korean Gastronomy: "Korean Edible Insect Laboratory" Case Study

Jungyoung Tiffany Shin, Melissa A. Baker, and Young Wook Kim

Abstract The aim of this chapter is to explain changes in South Korean gastronomy involving edible insects. This chapter begins by exploring the past use of edible insects in the Korean diet; identifying the reasons for their decreasing portion of Koreans' diets. Then, it investigates the current use of edible insects by using a case study from the Korean Edible Insect Laboratory (KEIL). Using this case study, this chapter highlights how to overcome consumer resistance and involve wider ranges of stakeholders in order to increase the sustainable edible insect food system. This chapter ends by projecting future changes in Korean gastronomy and the use of edible insects.

1 South Korean Gastronomy, History, and Insects as Food

Human lives and insects are closely related. According to the Korean National Institute of Environmental Research (2012), despite individuals' negative perceptions of insects, only 1–5% of living insects are harmful to humans and the rest tend to harmoniously coexist with human beings. This statement provides important insights into the history of Korean gastronomy and the use of edible insect as food.

Perhaps the most well-known historical record of edible insects was a medical book called "Donguibogam" written by Jun Heo, the greatest Eastern medicinal physician (1546–1615) in Korean history. In this book, Dr. Heo recorded the use

J. T. Shin (✉)
Conrad N. Hilton College of Hotel & Restaurant Management, University of Houston, Houston, TX, USA
e-mail: jslegendre@uh.edu

M. A. Baker
Department of Hospitality and Tourism Management, Isenberg School or Management, University of Massachusetts, Amherst, MA, USA
e-mail: mbaker@isenberg.umass.edu

Y. W. Kim
Korean Edible Insect Laboratory, Seoul, Republic of Korea

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_10

of 95 different types of medicinal edible insects that exhibit the effectiveness of curing of certain illness. For example, grasshoppers were used to heal bronchitis and asthma, and crickets were used to alleviate symptoms involving the liver and fever (Kim 2014). Edible insects, however, were not only limited to medicinal uses in Korea and were regularly consumed as food.

In comparison to today's Korean society, edible insects were more prevalent in Korean diets in the past. During the post-Korean War period, the economy of Korea was heavily reliant on agriculture. Therefore, grasshoppers and crickets were plentiful in the rice fields, and silk worms were abundant in the market because Korea's silk industry was prosperous during that time (Kim 2014). However, under former president Chung-hee Park's regime in the 1970s, the Korean government implemented a 5-year economic development plan, which placed significant emphasis on the industrialization of the Korean economy. As a result, the agriculture sector as well as the silk industry faced a steep decline (Datta and Nanavaty 2005). Further, it led to a decrease in insect populations and significantly reduced insects from the Korean diet due to the reduced agricultural lands.

Institutional changes reduced the edible insect population and caused a decrease in edible insect consumption, resulting in the lack of exposure to edible insects growing up, a limited contact with insects among younger consumers, and a dietary division between younger and older generations (Han et al. 2017). Such changes led younger generations to gain entomophobia (the "yuck" factor) which is defined as individuals' general fear toward insects (Milosevic and McCabe 2015). This becomes a negative factor when edible insect foods appear back on their dining tables because entomophobia can become even more pronounced if it is combined with food neophobia. Food neophobia is a personality trait that refers to the "reluctance to eat, or the avoidance of, new foods" (Dovey et al. 2012, p. 183). Therefore, a combination of entomophobia and neophobia trigger strong rejections especially among those who have not been exposed to edible insects in their early childhood (Moding and Stifter 2016).

Another noteworthy aspect is the influx of Western food culture after the World War II and the Korean War (Pettid 2008). During modernization, Korean consumers' perceptions of eating insects were changed from "normal" to "primitive or underdeveloped". In regards to this, some argue that Eastern countries' eating insect culture was misinterpreted by the Westerners and perceived as uncivilized acts (Morris 2004; Kim 2014). As a result, young Koreans who were born and grew up in the more Westernized culture were influenced by these stereotypical images of edible insect consumption and potentially perceive eating insects as uncivilized or primitive (Kim 2014). Such a shift caused distinctive food consumption patterns across the different generations of Koreans. Consequently, the Korean diet became more dependent upon livestock and/or seafood sourced protein and farmers needed to pursue their businesses in accordance with consumer demand.

2 Present Use of Insects: Evidence from the Korean Edible Insect Laboratory (KEIL) Case

Changes in the industry structure, loss of agricultural lands, decrease in insect population, generational division, and negative cultural connotations attached to eating insects inevitably caused difficulties in bringing back insects to Korean dining tables. Moreover, with technological advancement and abundance in food variety, today's Koreans do not see the value or understand the rationale behind the eating insects. Therefore, convincing younger generations to consume edible insects become a hard battle that requires detailed strategies (Kim 2014). To demonstrate strategic approaches to the popularization of edible insects in Korea, this chapter adopts an business case from South Korea.

2.1 Justification for the Case Selection

In South Korea, the edible insect market (food, medicinal, and animal feed markets all combined) was valued at less than USD 143 million in 2011 when KEIL was founded (Kim et al. 2015). KEIL is the first Korean research-based company to produce edible insect based protein materials (e.g., edible insect powder, oil extracts, allulose). The company has made a range of endeavors to create consumer demand and to incorporate all business stakeholders. KEIL mass produces insect based food protein materials (e.g., white-spotted chafer larva, mealworms, two spotted crickets, and rhino beetle larva alongside silkworms and rice grasshoppers) and has almost 90% market dominance. Their achievement resulted in the expansion of the overall edible insect market up to USD 259 million in 2015 (among these, KEIL created approximately 14.5 million edible insect food markets excluding pet food and medicinal markets) and it is projected to be USD 457 million in 2020 (Kim et al. 2015).

2.2 Company Introduction and Business Portfolio

KEIL was first founded in 2011 with a mission to popularize edible insects by providing safe and tasty food products; it also aims to contribute to global food security and help alleviate problems related to global hunger. The business has four pillars that support its core activities: (1) Research (product development, food science, consumer psychology, consumer trends, production, service, operation, and management), (2) Education (Western cuisine culinary program; advanced confectionary and bakery program), (3) Promotion (convention and events, media), (4) Restaurants (Papillon's Kitchen™), and (5) Humanitarian activities. Currently, the company produces cookies (double chocolate chip, mocha chocolate chip), macarons (green tea, raspberry, blueberry, vanilla, coffee), French financiers, energy bars, protein shakes, and soups (sweet potato, pumpkin, mushroom). In addition, the company produces flat bread to help reduce global hunger problems.

2.3 Commercialization of Edible Insects: Overcoming Barriers and Adopting a Stakeholder Approach

Stage 1: Initial Endeavor

After the Food and Agriculture Organization of the United Nations (FAO) released a report on edible insects (Van Huis et al. 2013), many entrepreneurs worldwide were interested in this venture (Tarkan 2015) – KEIL was one of those. In the beginning, KEIL thought it would be relatively easier to persuade Korean consumers than Western consumers (S. J. Jang (Department director at KEIL) personal communication, October 2, 2016) as eating insects has always been in Korean diet. Therefore, the first attempt was to highlight potential social, environmental, economic, nutritional, and health benefits of edible insects without restricting to one specific target segment. Promotional materials were developed and disseminated via online websites. However, the team identified that this was an underestimation of consumer entomophobia and the influence of the Western food culture.

Stage 2: Barriers of Entry and Research Collaboration

This novice approach to the commercialization of edible insect made KEIL to face major barriers – entomophobia/neophobia induced disgust, fear, and risk perceptions. At this stage, more in-depth understanding of consumer psychology, product development, and marketing efforts were needed. Therefore, KEIL collaborated with both international and domestic research organizations to explore more about the ways to overcome consumer rejections. In order to accomplish this goal, KEIL first collaborated with the marketing and consumer behavior researchers at the University of Massachusetts Amherst and the University of Houston. They examined the impacts of imagery and descriptive edible insect information on consumers' risk perceptions, intention to purchase, and liking of the products (Baker et al. 2016). In this study, US consumers who had had dining and retail purchasing experiences recently were included. The result of this study revealed that producing edible insect products in a processed form and with more ambiguous terminology (e.g., giant water bug vs. Nepomorpha; mealworm vs. Molitor) was more preferable than presenting products with actual insect images and descriptions. The findings were key to successful product launching.

Due to these findings, KEIL had to find ways to completely powder edible insects, especially, mealworms, crickets, grasshoppers, in order to reduce consumer disgust. Therefore, the company had to find methods to powder and process these edible insects and they also needed to investigate appropriate cooking methods. The powdering of edible insects was simple, however, the bigger challenge appeared during the development of appropriate cooking methods and recipes for edible insect dishes. In general, the protein in insects is not water-soluble and the cuticles (the shiny parts of insect body) preserve its shape even after the milling process. For these reasons, when it was included in the dough, it reduced the surface tension and elasticity enough to affect consumers' taste perceptions. Additionally, the unique odors and tastes coming from insects were difficult to eliminate. This aspect was particularly detrimental because it was difficult to find the balance between the insect powder and other ingredients.

Furthermore, in order to develop consumer food products/dishes, controlling for allergic reactions was critical. When people develop allergic reactions to certain protein sources, oftentimes, their past diet pattern and health conditions become the reasons for the allergic reactions (foreign protein). Therefore, given the fact that insects have been a disregarded/unfamiliar food source for younger Korean generations, it was fundamental to develop a protein structure that minimizes the allergic reactions to this unfamiliar protein source (*Note*: Some have noted that insects contain chitin and that it can trigger allergic reactions. However, the studies on possible allergens in edible insects is scant and this claim requires more solid research to confirm this assumption. In the meantime, studies suggest different preservation methods for insect consumption such as heating/cooling, acidifying, freeze-dried (Srinroch et al. 2015).

KEIL needed to find ways to overcome these challenges. Hence, they invested significant amounts of time and financial resources to establish an in-house food science lab to test for protein structures and protein extraction methods. As a result, KEIL developed a range of protein extraction methods that are currently in the process of acquiring patents. These methods enable KEIL to move away from the insect powdering method and allow them to overcome the challenges mentioned above.

With these endeavors, KEIL expedited the recipe development process. They developed 50 different recipes using edible insects (Kim 2014). Recipes included salads (e.g., crunchy bean curd mealworm salad), soups (e.g., mealworm minestrone, white-spotted flower chafer larva corn soup), pizza (e.g., cricket potato pizza), pasta/noodles (e.g., grasshopper noodles with black bean sauce; cricket carbonara), Korean food (e.g., bibimbap - beef was replaced with cricket powder; pajeon - white-spotted flower chafer larva seafood and green onion pancake), Chinese dumplings (e.g., grasshopper shaomai; mealworm spring roll), confectionery and bakery items (e.g., cricket pound cake; white-spotted chafer larva lemon madeleine; red ants, weaver ants mixed bubble choux).

These recipes became the basis for the opening of Papillon’s Kitchen™ in Seoul, Korea. Papillon’s Kitchen Shindang branch is the nation’s first experimental edible insect specialized restaurant that serves selective menu items within the list of recipes developed in the previous process (Doo 2015). Removing the distinctive insect appearance and incorporating insects in the consumers’ familiar recipes brought market success. The Korean media was the first to show interest in KEIL’s business activities. Korean minor and major media channels were interested in the rationale behind using edible insects. KEIL had to act as an advocate of insect eating and disseminated edible insect knowledge to the general consumers through mass media, social media, and food blogs. Figure 1 shows menu items of Papillon’s Kitchen™.

Stage 3: Government and Policy Makers

Despite the media attentions and consumers’ interests, there was another problem in promoting edible insect eating – government regulations and policies around edible insects. In the past, under the South Korean Food and Drug Administration’s policies, South Koreans could use only two types of edible insects; rice grasshoppers and silkworms. Such strict regulations around using edible insects became a major barrier for farmers and business practitioners in terms of financial risk management. For farmers, especially in the livestock rearing sector, changing their businesses to

Fig. 1 Edible insect menu presentation at Papillon's Kitchen™

insect farming was concerning as the profit structure depends on only two insect species – product diversification might be impossible in this case. This means that if poor pest control resulted in both insects' getting diseases, there would be no other alternatives (Han et al. 2017). For business practitioners, especially the ones searching for new source of protein, this was a major limitation for investment.

Therefore, there was an urgency to persuade South Korean government to reconsider the regulations around edible insects farming. With mass and social media attention, the government was aware of these issues. In 2015, the KEIL, participating government bodies, business entities, and farmers were invited to the 'Regulations Renovation Conference with the President' at the blue house (Cheong Wa Dae – an official government building) and a direct suggestion was made to deregulate more edible insect species. As a result, South Korean government deregulated four more types of edible insects and allowed farmers to diversify their farming portfolio. Therefore, a total of six species were added to Koreans' dining table in 2016, these were white-spotted chafer larva, mealworms, two spotted crickets, and rhino beetle larva alongside silkworm and rice grasshoppers (Han et al. 2017).

Stage 4: Involving Corporations, Distribution Channels and Enabling Mass Production

Although KEIL achieved their business goals, the underlying problem that caused South Koreans not to eat edible insects was not completely resolved – a lack of exposure and accessibility. This indicated that the distribution channel of edible insect products was only reaching certain demographics. However, in order to achieve the environmental goals of reducing methane gas production

Table 1 Major collaborations and achievements

Collaborating Company	Achievements
CJ	Protein-based material research & development collaboration
Jeongpoong (subsidiary of Daesang Corporation)	Product development: Retort soup and sales (e.g., pumpkin, mushroom, and sweet potato) and edible insect ice-cream
Daehan Feed Co., Ltd.	Edible insect processing, and flour-based product development – quality standardization; production cost reduction Pet food development, production, and sales (for cats and dogs)
Korea Matsutani Corporation	Confectionery item production (e.g., cookies)
Hanaro Mart	Product distribution
Nutri-rice	Functional rice development – e.g., high protein rice
intoCNS	MiroWaro™ edible insect based pet food was developed and released through animal clinics nation-wide (*Note*: MiroWaro™ is positioned as a premium product that adopts "rawganic" approaches to the pet snack; Rawganic is superior form of pet snack that utilizes the same food ingredients used for human consumption)
CoffeeNie Cafe	Cookies and energy bars are distributed to approximately 200 franchised stores nationally
Ministry of Agriculture, Food and Rural Affairs (MAFRA)	Funds received from these two organizations provide sensory education for children and family members MAFRA granted permission to KEIL to issue edible insect cuisine specialized cook licenses (after pursuing their specialized culinary education programs)
Korea Agency of Education, Promotion and Information Service in Food, Agriculture, Forestry and Fisheries	

and to promote more sustainable farming, it was critical to provide greater consumer access to edible insect products and services.

KEIL looked for ways to improve their distribution channels and explored ways to enable mass edible insect farming and production. However, it required support from bigger corporations that have power to disseminate edible insect products to nationwide. At this point, the collaborations with bigger sized retail and food service companies were inevitable. To do so, KEIL signed contracts with the CJ group (the biggest food company in South Korea), Jeongpoong (a subsidiary of Daesang corporation; one of the biggest food companies), Daehan Feed Co., Ltd. (a company that is specialized in wheat flour and noodle production), Korea Matsutani corporation (starch specialized company), Hanaro-mart (one of the nation's biggest supermarkets), Nutri-rice (an agricultural corporation that has a wide range of health and nutrition enhanced rice varieties), the intoCNS company (it has the biggest IT system platform for domestic animal clinics), CoffeeNie Cafes (has approximately 200 branches nation-wide), Ministry of Agriculture, Food and Rural Affairs, and Korea Agency of Education, Promotion and Information Service in Food, Agriculture, Forestry and Fisheries. Table 1 shows the specific achievement KEIL acquired.

Fig. 2 Examples of KEIL material products

With these collaborations, KEIL's production, research, development, and sales capacities were enhanced and their diversified food products could be distributed all around the nation. Based on these endeavors, consumers gained improved access to edible insect products. Moreover, these collaborations enabled KEIL to move towards the material market rather than the end-product market. This meant that KEIL could focus on developing edible insect materials to be used for the final consumer food products and actively utilize competencies of the existing food companies. Additionally, with more significant financial margins, KEIL could develop new product package designs that are more appealing to the consumers and was able to acquire more repeat consumers. Figure 2 shows examples of KEIL's edible insect materials.

Finally, the last concern for KEIL was mass farming and production. To enable mass farming and mass production of insect-based food products, KEIL had to work closely with existing farmers. The major issue arose from quality control that can only be achieved with a more systematic approach. These issues included pest control in insect farming, product clinical trials, and heat-drying methods (edible insect quality can be compromised based on the heat-drying methods).

Therefore, for more systematic approach to the mass production, KEIL added Konkuk university (clinical trials for animal food product development) and Chonnam university (microbiology, pest-control, genetics for mass farming) to their collaborative networks. Finally, KEIL has been investing its funds in mass insect heat-drying machine for consistent quality production and they expected to launch the product by early 2017 (S. J. Jang, personal communication, November 12, 2016).

Stage 5: Sustainable Business, Education, and Corporate Social Responsibility

Aside from accessibility and scarcity related issues, another prominent reason for edible insect elimination in Korean diet was due to “unfamiliarity” and a “lack of education”. Therefore, to completely be away from these reasons and to contribute more to the sustainable business development, KEIL implemented a wide range of educational programs for young South Koreans.

According to the food neophobia literature, children around 4.5 years old begin to develop food neophobia and if a child does not have an exposure to certain food types during this period, they are more likely to develop food neophobia (EBS Children’s Dinning Table Production Team 2010). For this reason, educational programs for early age groups became essential. KEIL has been using Pappilon’s Kitchen™ as a sensory educational place where children could come and touch, eat, cook, and play with insects.

Additionally, KEIL received government funds from the Ministry of Agriculture, Food and Rural Affairs; the Korea Agency of Education, Promotion and Information service in Food, Agriculture, Forestry and Fisheries. These funds were used to provide edible insect sensory education for children and families. KEIL has also launched new certification programs that are aimed to train cooks to incorporate edible insects in their new recipes. Two official programs are provided; (1) Western cuisine culinary training program, (2) confectionery and bakery training program. Both programs are designed to last for 12 weeks. In the Western cuisine culinary training program, trainees can learn how to cook with edible insects. Attendees are trained with items such as soup, salad, pasta, pizza, and lasagna. In confectionery and bakery training track, participants can learn how to make macarons, cookies, pies, cakes, brownies, and cupcakes. Figure 3 shows the pictures of KEIL’s sensory educations (e.g., presenting edible insect dishes in the Seoul Cooking Show contest, cooking insects with families, baking edible insect cookies with children, and tasting insect based food).

KEIL emphasized that this whole journey began as Van Huis et al. (2013) addressed the environmental urgency of using edible insects. Therefore, one of KEIL’s missions was to contribute to global food security and hunger alleviation. To deliver this promise, KEIL agreed to collaborate with missionary NGO organizations that work closely with African countries. In 2015, August, KEIL donated 5000 “Hope” flatbreads and 200 energy bars to undernourished children in Tanzania (children between 5 and 10 living one hour away from Dodoma that could not afford

Fig. 3 Education programs

Fig. 4 “Hope” flatbread sent to Tanzania

to have at least one meal a day). Each flatbread contains approximately 8–10 g protein and a child’s consumption of 4 of these is sufficient for his or her recommended daily protein intake (35 g). KEIL is currently searching for more sustainable food security approach to Tanzanian children. If the opportunity permits, KEIL hopes to transfer their edible insect baking skills to Tanzanians and help them to mass produce edible insect flatbread to address undernutrition issues in children (Kim 2015). Figure 4 shows KEIL’s “Hope” flatbread project.

2.4 Implications from the Case Study

During the first edible insect conference held in Detroit (Eating Insects Detroit 2016), one of the frequently mentioned issues involved in the commercialization of edible insects was the “disgust” factor and consumer rejection. Many business organizations were looking for effective strategies to overcome this factor and move toward more sustainable business success which ultimately help with the food security and the world’s hunger problem human beings are facing. KEIL’s case provides some meaningful managerial implications for edible insect start-up companies world-wide.

First, to effectively diminish the impact of disgust and unfamiliarity, it is important to understand why edible insects are not involved in today’s diet. In South Korea’s case, it was due to a decrease in agriculture activities and insect population, and the influence of Western food culture. Therefore, to decrease the phobia involved in edible insect consumption, it is essential to provide consumers more exposure and accessibility to the products and insects. For the long-term effect on reduction of unfamiliarity, education opportunity in early age is critical and family-oriented environment can be more effective as it influences both children and parents.

Secondly, it is clear that scientific and research-based approaches are rudimentary to business success. In KEIL’s case, their major inquiry was how to decrease consumers’ risk perception toward edible insects (Baker et al. 2016). As a result, powdering or extracting necessary nutrient from edible insects and making the descriptions ambiguous can effectively reduce consumer rejections. However, this requires significant scientific knowledge and technological skills to improve the quality of insect food products. Smaller businesses with small capital might consider collaborative opportunities with large corporations.

Thirdly, stakeholder involvement seems to be a recipe for more sustainable edible insect gastronomy implementation. Donaldson and Preston (1995) addressed that merely considering suppliers, investors, employees, and consumers does not sufficiently provide business sustainable strategies, rather involving all participating stakeholders is critical for creating more values for customers and achieving business sustainability. Drawing upon KEIL’s case, this theory can also be applied to the edible insect businesses. To have more a sustainable environmental impact and improve the food security of the world, it is pivotal for individual companies to sustain their businesses and provide more abundant accessibilities to consumers. Therefore, participating industry practitioners need to involve not only directly related stakeholders but also governments, political groups, trade associations, and communities altogether to achieve better results.

Lastly, participating parties of edible insect industry should not forget that this whole idea emerged because of the urgency of environmental, hunger, malnutrition, and food security issues. Therefore, businesses should always consider ways to reduce the environmental impact on protein supply and also should have a mission to contribute to the lowering human starvation rate and improve global food security. In other words, the idea around edible insect should require practitioners to have globally and futuristic mindset and be responsible for environmental impacts of the business operations.

3 Future Use of Insects

The edible insect industry in South Korea is becoming more advanced. In 2017, the Korean edible insect industry successfully developed technology to extract necessary nutrients from insects (not powdering insects anymore) and can include the core nutrients in other product categories such as functional foods and medicine. The industry is now projecting possibilities to use these extracts for medical purposes to cure certain illness and/or potentials to enhance existing foods' nutrients contents. For example, such development can potentially help patients who have issues with digestive systems by providing them liquid food that has high nutrition contents.

Moreover, with this extraction of nutrient compounds, it is now possible to develop additives to enhance flavors of existing food products. For instance, extraction of glutamic acid can add savory taste to the dish and can potentially enhance flavors. Finally, perhaps not directly related to the food aspects, however, experts are considering the ways to use these extracts as cosmetic enhancer and help consumers to possess more healthy skin.

References

Baker MA, Shin JT, Kim YW (2016) An exploration and investigation of edible insect consumption: the impacts of image and description on risk perceptions and purchase intent. Psychol Mark 33(2):94–112

Datta R, Nanavaty M (2005) Global silk industry: a complete source book. Universal Publishers, Boca Raton

Donaldson T, Preston LE (1995) The stakeholder theory of the corporation: concepts, evidence, and implications. Acad Manag Rev 20(1):65–91

Doo R (2015) Insects, food of the future?: creative insect-based dishes, dessert and insect farms on the rise. The Korea Herald. Available from http://www.koreaherald.com/view.php?ud=20151120000841. Accessed 12 Oct 2016

Dovey TM, Aldridge VK, Dignon W, Staples PA, Gibson EL, Halford JC (2012) Developmental differences in sensory decision making involved in deciding to try a novel fruit. Br J Health Psychol 17(2):258–272

EBS Children's Dinning Table Production Team (2010) Children's diet. Knowledge Channel Publication, Seoul

Han R, Shin JT, Kim J, Choi YS, Kim YW (2017) An overview of the South Korean edible insect food industry: challenges and future pricing/promotion strategies. Entomol Res 47(3):141–151

Kim EH (2015) "Hope" flat bread project. Food & Healthy Life Essen. Available from http://smlounge.co.kr/essen/article/23921. Accessed 13 Oct 2016

Kim YJ, Han HS, Park YG (2015) Future plans for the Korean edible insect industry. Korea Rural Economic Institute. Available from http://www.krei.re.kr/web/www/23?p_p_id=EXT_BBS&p_p_lifecycle=1&p_p_state=exclusive&p_p_mode=view&p_p_col_id=column-1&p_p_col_count=1&_EXT_BBS_struts_action=%2Fext%2Fbbs%2Fget_file&_EXT_BBS_extFileId=6001. Accessed 12 Oct 2016

Kim YW (2014) The 50 ways to cook edible insects. Bumwoo Publication, Seoul

Korean National Institute of Environmental Research (2012) Insects around us, Koreans. Government Printing Office, Seoul

Milosevic I, McCabe RE (2015) Phobias: The Psychology of Irrational Fear: The Psychology of Irrational Fear. Santa Barbara, CA: ABC-CLIO.

Moding KJ, Stifter CA (2016) Stability of food neophobia from infancy through early childhood. Appetite 97:72–78

Morris B (2004) Insects and human life. Berg Publishers, Oxford

Pettid MJ (2008) Korean cuisine: an illustrated history. Reaktion Books, London

Srinroch C, Srisomsap C, Chokchaichamnankit D, Punyarit P, Phiriyangkul P (2015) Identification of novel allergen in edible insect, Gryllus bimaculatus and its cross-reactivity with Macrobrachium spp allergens. Food Chem 184:160–166

Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects: future prospects for food and feed security. Available via the Food and Agriculture Organization of the United Nations website: http://www.fao.org/docrep/018/i3253e/i3253e.pdf. Accessed 28 Sept 2016

Tarkan L (2015) Why these starups want you to eat bugs. Fortune. Available from http://fortune.com/2015/08/25/edible-insects-bug-startups/. Accessed 23 June 2017

Part V
Environmental Impacts, Conservation and Future Challenges

Comparing Environmental Impacts from Insects for Feed and Food as an Alternative to Animal Production

Afton Halloran, Hanne Helene Hansen, Lars Stoumann Jensen, and Sander Bruun

Abstract This chapter systematically compares and contrasts the known environmental impacts of traditional vertebrate animal production with insect production intended for both food and animal feed. There are major physiological and biological differences between traditional livestock species and insects, which often translate into lower environmental impacts from insect production. However, insect production systems are still in their infancy and there are still major improvements to be made. Based on our analysis, the greatest potential of insects is the prospect of feeding them various kinds of waste products from agriculture, industry and households. This chapter can serve as a reference guide for future research into the environmental impacts of insects for food and feed.

1 Introduction

Animal production is associated with a variety of environmental impacts. As a result of economic growth and dietary transition there is a rising global demand for animal products, like beef and cheese (Robinson and Pozzi 2011). The extent of the environmental impacts vary depending on a number of factors including species, farming system/production method under consideration, levels of consumption, nutritional value, feed composition and production period (de Vries and de Boer 2010; Tilman and Clark 2014).

A. Halloran (✉)
Department of Nutrition, Exercise and Sports, University of Copenhagen, Frederiksberg C, Denmark

H. H. Hansen
Department of Plant and Environmental Sciences, University of Copenhagen, Frederiksberg C, Denmark

L. S. Jensen · S. Bruun
Department Veterinary and Animal Sciences, University of Copenhagen, Frederiksberg C, Denmark

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_11

The environmental impacts of animal production also depend greatly on the type of digestive system of the animal in question. Production systems based on monogastric animals require high protein, easily digestible feed to achieve sufficiently high growth rates. The production of the high protein feed, especially soy beans, is associated with significant environmental impacts because they are often grown in regions where their production indirectly affects or directly encroaches sensitive ecosystems. Ruminants have a significant advantage over the monogastric animals in that they are able to metabolize and utilize cellulose and hemicellulose, and hence can digest more recalcitrant forage. However, this is problematic in that a by-product of this digestion is the potent greenhouse gas methane.

Insects, on the other hand, are physiologically and biologically different from other animal species. Insect metabolism does not require a constant body temperature like the vertebrate species traditionally used for human consumption. This means more efficient use of resources such as feed and water.

In this chapter, we systematically compare and contrast the known direct environmental impacts of traditional vertebrate animal production with insect production for both feed and food. We also discuss room for improvement and knowledge gaps to enhance our understanding of the comparative advantages of insect production systems over traditional animal production systems. The following traditional impact categories will not be discussed within this chapter, as they are considered of no or very minor relevance for the topic: ionizing radiation, ozone depletion, photochemical ozone formation.

2 Acidification

The main contributor to acidification and particulate matter formation from protein production is ammonia (NH_3), which is one of the reactive nitrogen (N_r) species in the overall nitrogen cycle of the biosphere (Sutton et al. 2011). Nitrogen enters protein production through fertiliser and biological N fixation by crops, which are then used as feed for animals.

2.1 Ammonia

Ammonia emissions and subsequent deposition have an impact on soil acidification (through nitrification in which ammonium is oxidized to nitrate under the production of hydrogen ions) and eutrophication of terrestrial and aquatic ecosystems. Furthermore, ammonia emissions contribute to formation of fine particle pollution ($PM_{10/2.5}$) of the atmosphere.

2.1.1 Animal Production

Animal feed N conversion efficiency varies greatly between different animal species, from less than or 20% for cattle, around 20–30% for pigs and 30–40% for poultry (Steinfeld et al. 2006). This variation results in a large variation in the proportion of N excreted as ammonium and organic N (100%-feed N conversion efficiency%). This means that loss of ammonia derived from animal manure and urine is substantial. According to Leip et al. (2015), 82% of all ammonia emissions in EU agriculture stem from livestock production. Nitrogen emissions also vary greatly between production systems (incl. feeding) and manure management, especially animal housing, manure storage and field application methods. Typical ammonia volatilisation from housing and manure storage from intensive livestock production systems has been estimated at around 20% of excreted total N, and an additional 20% may be lost during field application (Steinfeld et al. 2006). N volatilization may be significantly reduced by low-emission housing, storage and application technologies, such as ventilation air scrubbing, covered slurry tanks and slurry injection or acidification technologies. Hutchings et al. (2014) quantified the overall N flows and balances of Denmark in 2010, where advanced low-emission technologies have been in implemented in agriculture over the past three decades, and found overall ammonia emission to be as low as 21% of excreted manure N.

An important difference between mammal livestock and poultry is that mammals mainly excrete nitrogen as urea whereas poultry excrete nitrogen mainly as uric acid (Sommer and Hutchings 2001). Urea is quickly hydrolysed to ammonium after excretion, leaving it prone to volatilization, whereas the oxidation of uric acid is much slower. This typically results in lower free ammonia concentrations in poultry litter and means that ammonia loss from is generally less but more variable, depending on storage conditions and time, compared with other types of manure.

2.1.2 Insect Production

Similar to production systems based on vertebrate animals, ammonia emissions are also likely to occur from many types of insect production systems. To achieve fast growth, feed with high protein content is often used in these systems and this also means that excess nitrogen is likely to be excreted by the insects. Like birds, most insects excrete nitrogen as uric acid. Usually the insect excreta, or frass, are rather dry, which also means that the conversion of the uric acid to urea and ammonia should be relatively slow, thereby reducing ammonia emissions. During storage, emissions will depend very much on storage conditions, temperature, pH and moisture. Uric acid conversion could be rapid and significant and thus result in significant loss of ammonia if the manure is stored with exposure to moisture, but no actual measurements on insect frass are available to support this for insects.

Very little empirical data exists about ammonia volatilization from entire insect production systems. Oonincx et al. (2010) found ammonia emissions of five insect species[1], suitable for animal and human consumption, to be lower than emissions from beef cattle and pigs. For example, the ammonia emissions of pigs are eight to twelve times higher per kilo of growth when compared to *Acheta domesticus*, and up to fifty times higher than *Locusta migratoria*. Under most circumstances ammonia loss can probably be assumed similar to or lower than for poultry given the fact that the dry matter content is higher than in poultry manure (Halloran et al. 2017).

3 Climate Change

When compared to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have considerably greater global warming potentials (GWPs). In order to express the GWP on a CO_2-equivalent basis, the Intergovernmental Panel on Climate Change assigns CO_2 a GWP of 1 CO_2-eq. In comparison, CH_4 has a GWP of 25 CO_2-eq, and N_2O has a GWP of 298 CO_2-eq. (IPCC et al. 2007). Herrero et al. (2016) estimate that the livestock sector was responsible for GHG emissions of 5.6–7.5 Gt CO_2-eq. per year between 1995 and 2005.

In a life cycle assessment, Halloran et al. (2017) found that cricket farming had a lower GWP than broiler chicken farming. When looking across the spectrum of GWPs attributed to animal source foods (Fig. 1) one can see that broiler chicken farming in Thailand has a lower global warming potential than pork, beef, and lamb but a higher global warming potential than farmed salmon, mealworms, chicken production in Denmark, crickets and wild herring. While there is large disparity in the data (even data within livestock categories), cricket farming is one of the most environmentally sustainable animal source food production systems available.

3.1 Methane Gas Emissions

3.1.1 Animal Production

On a worldwide basis, livestock production is estimated to produce 14.5% of all anthropogenic GHG emissions (Herrero et al. 2011). Beef and milk production from cattle account for the majority (41% and 20% respectively) of the livestock's sector's emissions, while pig meat and poultry meat and eggs contribute a total of about 17% (9% and 8% respectively) (Gerber et al. 2013). Methane is a product of normal anaerobic fermentation of feedstuffs in the animal or feedstock in collected

[1] *Tenebrio molitor*, *Acheta domesticus*, *Locusta migratoria*, *Pachnoda marginata,* and *Blaptica dubia*

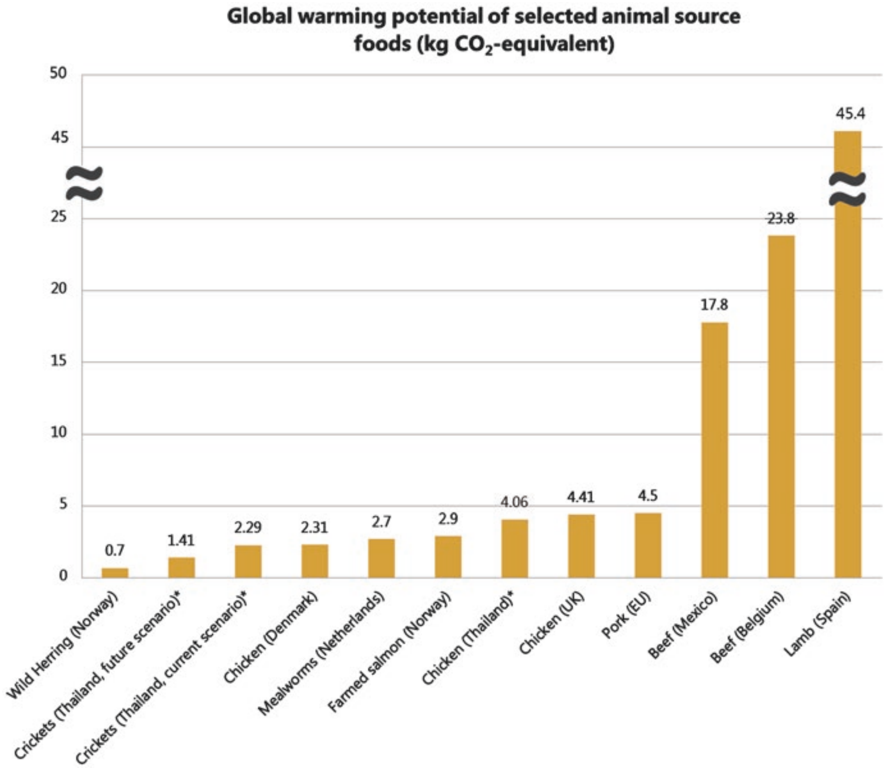


Fig. 1 Comparison of the global warming potential (kg CO_2-e) of selected animal source foods per kg of edible mass (*indicates results from Halloran et al. 2017, and pork (EU), beef (Belgium) and lamb (Spain) were based on an average of different production systems) (Sources: Halloran et al. 2017; Jacobsen et al. 2014; Kool et al. 2010; Leinonen et al. 2012; Nielsen et al. 2012; Oonincx and de Boer 2012; Ripoll-Bosch et al. 2013; Rivera et al. 2014; Winther et al. 2009; Ziegler et al. 2013))

manure. Methane is produced by methanogenic microbes of the taxonomic domain: Archaea. These microbes use either the acetate or the carbon dioxide and hydrogen produced during carbohydrate degradation to produce methane. This process prevents H_2 buildup that will stop the digestion process in the animal. The produced methane can be a source of biogas energy when fermenting manure, but the methane expelled from the rumen or hindgut is a loss of feed energy to the animal. The amount of total gas produced during digestion varies greatly according to the total feed intake. The proportion of methane produced varies due to the carbohydrate composition of the feed, which in turn helps determine the microbial population. Abatement measures via animal breeding, production management, dietary strategies and microbial manipulation are the subject of much research (Eckard et al. 2010).

3.1.2 Insect Production

Methane production also occurs in the guts of some insects. Termites (Isoptera) are responsible for between 5% and 19% of total CH_4 emissions globally (Jamali et al. 2011). Methanogenic archaea can also be found in the proctodeum (hindgut) of most tropical representatives of millipedes (Diplopoda), cockroaches (Blattaria), and scarab beetles (Scarabaeidae). Other arthropod taxa do not appear to emit methane (Hackstein and Stumm 1994).

Very few measurements have been conducted from insects that are currently used for food and feed. In a study of the GHG emissions of five insect species, Oonincx et al. (2010) did not detect CH_4 emissions in *Acheta domesticus*, *Tenebrio molitor* or *Locusta migratoria.* However, *Pachnoda marginata* and *Blaptica dubia* (two insect species used as feeder insects for reptiles, birds, etc.) were found to produce more CH_4 than pigs but less than beef cattle per kg of weight gain. Halloran et al. (2017) detected insignificant levels of CH_4 in a farming system of *Acheta domesticus* and *Gryllus bimaculatus* in Thailand.

The reason for the low emissions from the tested insects is likely due to the fact that they are fed mainly on protein rich sources without cellulose to enable high growth rates. For this reason, they do not use microbes to breakdown cellulose or hemicellulose in their feed. However, in the future, other feed sources such as grass cuttings, household waste or maybe even garden waste is likely to be considered as feed sources for insects. These sources contain cellulose, hemicellulose and complex lignocellulose compounds and it is therefore likely that methane emissions may be a problem from these systems.

3.2 Nitrous Oxide Emissions

3.2.1 Animal Production

As opposed to methane emissions that occur as a product of feed degradation in the animal or in the manure, nitrous oxide (N_2O) emissions come primarily (90%) from agricultural crop, soil and waste management practices (Eckard et al. 2010). Nitrous oxide is mainly produced in agricultural fields through the two nitrogen transformation processes of nitrification and denitrification. The emissions ascribed to animal production are therefore related both to the production of feed and the nitrous oxide emissions occurring as a consequence of fertilizers used for the crop as well as the nitrous oxide emissions occurring as a consequence of the application of manure on agricultural fields. The scope of the total worldwide emissions is difficult to estimate, but expansion of agricultural lands and use of fertilizers (mineral and manure based) make a significant contribution (Reay et al. 2012). Galloway et al. (2010) estimated that on a global scale, agricultural activities contribute 57% of global N_2O emissions, and of this, two-thirds comes from land with intensive animal production systems.

3.2.2 Insect Production

As with vertebrates, the main emission of N_2O that must be ascribed to insect production systems occurs in the fields as a consequence of feed production and manure application. The denitrification process occurs under conditions of low oxygen content in soil. Therefore, it may be argued that N_2O emissions, after application of dry insect manure, would be less than when wet livestock manure is applied. However, it may turn out that the nitrogen will only be stored in the soil until the next rain event, whereafter denitrification would commence because the soil is temporarily depleted of oxygen. In conclusion, insects are only likely to be associated with lower N_2O emissions to the extent that they are more efficient at converting protein into animal protein as this will be reflected in both the amount of feed that needs to be produced and also the amount of manure that will be produced.

There are, however, also minor emissions of N_2O from the guts of both vertebrate animals and insects. *Locusta migratoria* were found to emit approximately half the N_2O per kilogram of growth than pigs, and *Acheta domesticus* emitted one quarter less (Oonincx et al. 2010). Another study found that farmed *Acheta domesticus* and *Gryllus bimaculatus* emitted insignificant levels of N_2O (Halloran et al. 2017). No other studies have measured the direct N_2O emissions from insects for food and feed.

3.3 Carbon Dioxide Emissions and Carbon Sequestration

3.3.1 Animal Production

Carbon dioxide (CO_2) emissions due to animal respiration is generally not considered when calculating greenhouse emissions (Steinfeld et al. 2006). This is because the respired carbon is considered to be offset by the carbon dioxide fixed by photosynthesis during production of the forage used for feed. However, animal production contributes to CO_2 emissions due to effects on soil organic carbon stocks, e.g. through land use change (e.g. from native vegetation to grassland, or grassland to cropland), but also contributes to net CO_2 binding through soil carbon sequestration from e.g. manure application to arable land (Menzi et al. 2010). The dominant impact of livestock production at the global scale comes from tropical deforestation for pasture and croplands and soil degradation/desertification (Asner and Archer 2010). The potential of carbon sequestration due to grazing land management has been researched, but with widely differing results, that have polarized the scientific community (Steinfeld et al. 2006). If grazing management can remove dead or unproductive forage and allow more, new vegetation, this may lead to larger residual carbon inputs, and the balance of soil carbon sequestration will be in favor of grazing as opposed to no grazing. However, methane production from the grazing animals or nitrous oxide emissions and fossil fuel energy use if the alternative to grazing is crop production must be considered respectively against and in favor of grazing as well (Asner and Archer 2010).

3.3.2 Insect Production

Most of the mechanisms leading to emissions of CO_2 for vertebrate production systems will also be active for the insect production systems. Production of insect feed leads to CO_2 emissions through land use change if natural systems are converted to cropping systems. The conversion process releases the stored carbon as CO_2. Cropping systems based on grass contain more C than systems based on annual crops and may therefore be less problematic in terms of CO_2 emissions. For this reason, insect production systems will be very similar in terms of CO_2 emissions, to the vertebrate systems that are based on the same feedstuff. However, to the extent that insects are more efficient at converting feed into animal protein, the emissions may be smaller.

Energy-related CO_2 emissions are also noteworthy. Halloran et al. (2016) noted that energy consumption in insect production depends heavily on the kind of production system in question as well as the geographical location of the farm, with the same information applying to animal production. Oonincx and de Boer (2012) found that mealworm production in the Netherlands consumed significant amounts of energy for heating. However, larger mealworms were also found to produce surplus heat which, in turn, generated heat for the smaller mealworms, thus large scale production of insects may require much less heating even in colder regions. The need for heating is influenced by the conversion efficiency of the insect species and the density of insect biomass in question.

4 Ecotoxicity and Human Toxicity

Toxicity to either humans or ecosystems may be caused by various aspects of vertebrate or insect protein production. This can occur from pesticides, herbicides or other chemicals used in feed crop production, mineral additives used in animal feeds, or medicinal residues from drugs used to treat diseases in livestock. Some countries allow growth promoters, which can be excreted and may be endocrine disrupters in humans or have detrimental effects on aquatic organisms if the excrement pollutes waterways (Steinfeld et al. 2006).

4.1 Soil Contamination

4.1.1 Animal Production

Soil contamination from animal production derives mainly from the use of zinc (Zn) or copper (Cu) oxides in animal feeds as prophylactics against diarrhea, especially for weaners and piglets in swine production and for young birds in poultry production

(Menzi et al. 2010). Both elements are essential micronutrients for plants and animals, but can also be toxic for microorganisms, soil fauna, plants, and further through the food-chain to humans, when present in excess concentrations. Many countries with intensive animal production have lowered the requirement and therefore necessary use on Zn and Cu in animal feeds, and the EU is currently considering a complete ban on these, so the problem is expected to be reduced in the near future. The drawback of a required reduced use of heavy metal minerals as a prophylactics is a possible increase in the demand for other feed additives that may fulfill the same role, like antibiotics or antimicrobials. These could end up in the soil via manure application, with a potentially large ecotoxic effect on soil organisms.

4.1.2 Insect Production

As insect production is still in its infancy with only limited commercial production, very little is known about the need for and usefulness of prophylactic use of Cu and Zn oxides as well as antibiotics. The intestinal tracts of insects are completely different from mammals and birds and the need and the ability of these compounds to increase productivity in large scale production could range from unnecessary to important. The use of antibiotics and other medicine is known to be widespread in shrimp production, a large scale arthropod production system. It is, however, unlikely that the experience from these water-based systems can be translated into insect production. Some commercial cricket farms in the USA like Big Cricket Farms currently advertise their crickets as antibiotic and steroid free.

5 Freshwater, Marine and Terrestrial Eutrophication

Diffuse pollution of groundwater and surface waters with nitrogen (N) and phosphorus (P) is a problem in many regions of the world, especially in areas with intensive agricultural production. In surface waters (marine and fresh), these losses cause problems with eutrophication and algal bloom, and in areas that rely on the use of groundwater, high nutrient concentrations can be a problem for the potable water quality. For drinking water the EU limit has been set at a nitrate concentration at 50 mg L^{-1} (EU Drinking Water Directive, 98/83/EC). Nutrient losses to aquatic systems mainly occur by leaching through the soil profile and through surface runoff when the infiltration capacity of the soil is exceeded. Appropriate management and use of mineral fertilizers and organic residues is therefore essential for minimizing nutrient losses and the environmental impact of agriculture. Freshwater eutrophication is mainly caused by losses of phosphorus while marine eutrophication is caused by nitrate which to lost to surface water from where it eventually ends up in estuaries and coastal areas. Terrestrial eutrophication is mainly caused by loss of ammonia that is deposited in sensitive areas.

5.1 *Freshwater, Marine and Terrestrial Eutrophication*

5.1.1 Animal Production

Loss of nutrients to the aquatic environment occurs during production of feed for animal production, whether these are planted roughages for ruminants, or grains or other concentrated protein-and energy rich feed. The magnitude of these losses depends on a wide range of biophysical factors, such as level of nutrient input compared to crop demand, soil type, climate, crop rotation/ sequence and management (e.g. use of catch crops). Losses of N from feed crops are moderate only if mineral fertiliser is applied at adequate rates (Jarvis et al. 2011), typically less than 20% leaching loss of applied N.

5.1.2 Insect Production

As for animal production, production of feed for insect production systems will also result in losses of nitrate. The losses will therefore most likely only be smaller than for animal production to the extent that the insect metabolism is more efficient than livestock metabolism in terms of converting feed protein into animal protein.

5.2 *Manure Handling*

5.2.1 Animal Production

If animal manure, which contains substantial quantities of organic matter, N and P, is partly or fully used to supply the crop nutrient demand, losses may be large. This is mainly due to the organically bound N in manure which mineralises gradually, also at times where crops do not have a nutrient demand (Sørensen and Jensen 2013). This mineralisation is slow, so when manure is applied initially, losses are small, but with long term repeated applications the N losses may increase to 25–30% of the applied total N.

5.2.2 Insect Production

Currently, no study has analysed the fertilizer values of, or nutrient losses after application of insect manure. As described above a large proportion of the nitrogen could exist in the form of uric acid which is gradually mineralized in the soil after the manure has been applied. Therefore the manure is also likely to behave similarly to poultry litter which has a somewhat uncertain fertilizer value due to the moderate release rate and plant availability of the N (Jensen 2013).

6 Water Depletion

Water, in animal production, is consumed directly and indirectly as drinking water, feed ingredients and service water and used in some places for cooling. Miglietta et al. (2015) found that the water footprint per edible ton of mealworms was comparable to chicken meat. The water footprint of beef is approximately three times higher than mealworms (Miglietta et al. 2015).

6.1 Indirect Water Footprint of the Feed

6.1.1 Animal Production

The majority of water used along animal product supply chains occurs during the production of feed ingredients (Mekonnen and Hoekstra 2012). In fact, more than 8% of the global water usage is used by the livestock sector, with 7% of global uses going to the irrigation of feed crops for livestock (Schlink et al. 2010). Many of the major crops used for animal feed like soy and maize are grown in areas where there is a lack of water and are therefore supplemented by irrigation water. Therefore, it is the use of water demanding crops used for feed production and unfavorable feed conversion efficiencies of livestock which are, for the most part, responsible for the relatively large water footprint of animal products compared to vegetable products (Mekonnen and Hoekstra 2012).

6.1.2 Insect Production

The general higher efficiency of insect production compared to conventional livestock production means that less feed is needed. For this reason, the water footprint of insects also has the potential to be smaller than for vertebrate livestock. Other sources of feed which could be used for insects, especially different kinds of waste, could be give rise to production systems with a very low water footprint.

6.2 Direct Water Footprint Related to the Drinking Water

6.2.1 Animal Production

The consumption of water by production animals depends on many variables such as dry matter intake; diet composition; water availability and quality; water temperature; the ambient temperature and the production system in question. Water requirements are especially high for livestock under warm and dry conditions (Steinfeld et al. 2006).

6.2.2 Insect Production

Like livestock, the amount of drinking water that insects require is dependent on the food source and the climate. Being poikilothermic, insects do not rely on evaporation of water to keep their body temperature low. For this reason, they are much more frugal in terms of water consumption. Some desert insects can even survive solely on metabolic water i.e. the water which is released by oxidizing energy-containing substances in their food (Zachariassen 1996).

Murray (1968) suggests that *Tenebrio molitor* do not need additional drinking water when farmed under appropriate conditions of humidity and are provided with carrots and an optimal ratio of bran/grain. In Thailand, for example, crickets are usually supplied with small trays of water that are changed every few days. Overall, water consumption is low.

6.3 Service Water Consumed During the Farming Stage

6.3.1 Animal Production

Service water also varies between production systems. Industrialised animal production systems will inevitably require larger quantities of service water. Service water is used to clean pens/units, wash animals, cool down facilities as well as animals. Service water is also used for waste disposal, especially in pig production (Steinfeld et al. 2006).

6.3.2 Insect Production

In order to maintain a high standard of hygiene and prevent disease, pens which contain the insects must be cleaned regularly. Water use consumption for service water depends largely on the facility, housing structure and length of the insect life cycles. However, overall service water use should be lower for insect production than for animal production.

7 Resource Extraction

A range of critical and limiting resources are used for modern agriculture. The most significant ones include rock phosphate and crude oil. Rock phosphate is mainly used for production of fertilizer while crude oil is used for diesel production, which is subsequently used for a range of processes including field tillage, grain drying and processing. Livestock production is mainly responsible for the consumption of these resources through the use of feeds which require the use of phosphate fertilizer as well as work which is provided mainly by use of diesel.

7.1 Animal Production

Efficient recycling of animal wastes could reduce the huge need for phosphate in livestock feed production. Unfortunately, the production of feed is, to a great extent, spatially separated from the animal production. Although there are exceptions, animal waste is most commonly applied in the vicinity of the animal production. This means that phosphorus typically accumulates in the soils close to the animals while the soils from where the feed is produced are gradually depleted or have to be supplemented from mineral fertilizers produced from rock phosphate (Naylor et al. 2005). Accumulation of phosphorus in soils also means that the risk of runoff (via erosion and particulate transport on the surface) or leaching (dissolved/dispersed through the soil to drains and ground water) to the environment is increased (Steinfeld et al. 2006).

7.2 Insect Production

It is difficult to determine if insect production will also concentrate or deplete phosphorous or other resources in specific areas. The unfortunate separation is to a large extent more a consequence of socio-economic factors than it is a consequence of optimization of the production. Therefore insect production systems could be better in this respect or even worse – this will largely depend on the structural and economic development of insect production in the future.

8 Direct and Indirect Land Use and Land Use Change

Land use refers to the total amount of land required to produce a given good, which in the case of this chapter is meat, milk, eggs or insects. Land use not only refers to the land needed for grazing in either free range or planted pasture systems, but also the amount of land required for producing feed. Land use change refers to the human induced conversion of one land use to another. This, for example, could be the conversion of virgin forest or savanna to create farm land. Global dietary transition is one of the main drivers for an increased need for land resources and land use change (Alexander et al. 2015).

8.1 Animal Production

The livestock sector is a major user of land resources, representing approximately 30% of the world's surface land area (Steinfeld et al. 2006). Ruminants (e.g. sheep, goats and cattle) use the greatest amounts of land resources as they use both feed crops and graze natural or planted pasture. Trade-offs must be considered between the ability of livestock ruminants to convert human inedible cellulose to products for human use and uncontrolled manure expulsion and/or methane production. More land is needed when ruminants use marginal lands than from planted pasture or feed crops per unit product. Production efficiency per unit product increases while pollution per unit product can decrease when comparing ruminant production from grazing marginal lands with grazing planted pasture or planting crops. Despite the fact that both ruminants and monogastric livestock do not nutritionally require grazing, many countries take grazing and/or outdoor access into animal welfare and livestock ethical consideration.

Land required for the production of animal products has contributed to the majority of land use change (65%) over the past 50 years. According to Steinfeld et al. (2006), deforestation caused by expansion of pasture and feed crops generated 8% of the total anthropogenic CO_2 emissions. Land use change and biodiversity loss (Sect. 9) are therefore highly interconnected.

8.2 Insect Production

The production of the feed will be responsible for the majority of the land use and land use change for insect production systems. Oonincx and de Boer (2012) estimated that production of mixed grain feed was responsible for 99% of the land use in mealworm production. Smetana et al. (2015) estimated that the land use occupation of mealworm production to be 1.5–1.52 m^2 per kg. As feed production is responsible for the major part of the impacts, insect production is also efficient in terms of land use compared with traditional animal production to the extent that it is more efficient in terms of feed conversion.

9 Biodiversity Loss

The consumption of animal source foods is one of the greatest threats to biodiversity (Machovina et al. 2015). However, biodiversity loss is influenced by a complex web of variables that are, in turn, affected by multiple agents. It is therefore difficult to quantify the loss of biodiversity as a result of animal production (Steinfeld et al. 2006).

9.1 Animal Production

Livestock threaten biodiversity by modifying habitats; inducing climate change; influencing climate change; introducing invasive alien species, both directly and indirectly; overexploiting natural resources; and polluting ecosystems (Steinfeld et al. 2006). Livestock replacement of natural grazing animals has also been indicated as a loss of biodiversity (Alkemade et al. 2013) and grazing management a possible tool for biodiversity re-establishment, but scientific evidence is scant.

9.2 Insect Production

While there are over 2000 edible insect species (Jongema 2017), concentration on only a handful of edible species which could be farmed may draw attention away preserving the ecosystems where the majority of edible insect species are found. Further, the escape of non-native farmed species is of equal concern and threat to local biodiversity. Due to a lack of data on this issue, there is still a need for further studies into the dynamics of insect farming and biodiversity.

10 Conclusion

This chapter has systematically compared and contrasted the known direct environmental impacts of animal production with insect production for both feed and food. Clearly, animal production systems have substantial environmental impacts on the planet. However, switching part of the global animal production to insect production is clearly not a silver bullet which can solve all the problems associated with the production of animal protein, but, rather, holds the potential to reduce some environmental problems. In most cases the advantages are related to the fact that the insects are more efficient at converting feed into protein than other animals. This difference can be big in comparison to some products like beef and small in comparison with poultry meat.

Perhaps the greatest potential is the prospect of basing insect production on feed from various waste products from agriculture, industry and households. Insects are an extremely diverse group of animals and therefore it may be possible to devise systems based on insects that can digest more human inedible, fiber rich forage. If these systems are not hampered by the significant emissions of greenhouse gases and ammonia etc. that are associated with the digestive fermentation in ruminants, they could present a unique opportunity for producing animal protein in a more environmentally-friendly way. Finally, it may be possible to feed insects on waste products such as household waste, which could possibly improve their environmental sustainability. However, these systems have yet to be developed and therefore it is not known if the insects can achieve high enough growth rates for the systems to become economically viable.

Knowledge of the environmental impacts and experience with animal production systems is enormous in comparison to knowledge about insect production systems. In most cases, we can merely speculate on how the impacts would be different. For this reason, it is clear that more evidence is required to make comparisons between animal production systems and insect production systems.

References

Alexander P, Rounsevell MDA, Dislich C et al (2015) Drivers for global agricultural land use change: the nexus of diet, population, yield and bioenergy. Glob Environ Chang 35:138–147. https://doi.org/10.1016/j.gloenvcha.2015.08.011

Alkemade R, Reid RS, van den Berg M et al (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. PNAS 110:20900–20905. https://doi.org/10.1073/pnas.1011013108

Asner GP, Archer SR (2010) Livestock in the global carbon cycle. In: Steinfield H, Mooney H, Schneider L, Neville L (eds) Livestock in a changing landscape: drivers consequences and responses. Island Press, Washington, DC, pp 69–82

de Vries M, de Boer IJM (2010) Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest Sci 128:1–11. https://doi.org/10.1016/j.livsci.2009.11.007

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest Sci 130:47–56. https://doi.org/10.1016/j.livsci.2010.02.010

Galloway J, Dentener F, Burke M et al (2010) The impact of animal production systems on the nitrogen cycle. In: Steinfield H, Mooney H, Schneider F, Neville L (eds) Livestock in a changing landscape: drivers consequences and responses. Island Press, Washington, DC, pp 83–95

Gerber PJ, Steinfeld H, Henderson B et al (2013) Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome

Hackstein JH, Stumm CK (1994) Methane production in terrestrial arthropods. Proc Natl Acad Sci U S A 91:5441–5445

Halloran A, Roos N, Eilenberg J et al (2016) Life cycle assessment of edible insects for food protein: a review. Agron Sustain Dev 36(4):1–13. https://doi.org/10.1007/s13593-016-0392-8

Halloran A, Hanboonsong Y, Roos N, Bruun S (2017) Life cycle assessment of cricket farming in north-eastern Thailand. J Clean Prod 156:83–94. https://doi.org/10.1016/j.jclepro.2017.04.017

Herrero M, Gerber P, Vellinga T et al (2011) Livestock and greenhouse gas emissions: the importance of getting the numbers right. Anim Feed Sci Technol 166–167:779–782. https://doi.org/10.1016/j.anifeedsci.2011.04.083

Herrero M, Henderson B, Havlík P et al (2016) Greenhouse gas mitigation potentials in the livestock sector. Nat Clim Chang 6:452–461. https://doi.org/10.1038/nclimate2925

Hutchings NJ, Nielsen O-K, Dalgaard T et al (2014) A nitrogen budget for Denmark; developments between 1990 and 2010, and prospects for the future. Environ Res Lett 9:115012. https://doi.org/10.1088/1748-9326/9/11/115012

IPCC, Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK/New York

Jacobsen R, Vandermeulen V, Vanhuylenbroek G, Gellynck X (2014) A life cycle assessment application: the carbon footprint of beef in Flanders (Belgium). In: Muthu S (ed) Assessment of carbon footprint in different industrial sectors. Springer Science & Business Media, Singapore, pp 31–52

Jamali H, Livesley SJ, Dawes TZ et al (2011) Diurnal and seasonal variations in CH4 flux from termite mounds in tropical savannas of the Northern Territory, Australia. Agric Forest Meteorol 151:1471–1479. https://doi.org/10.1016/j.agrformet.2010.06.009

Jarvis S, Hutchings N, Brentrup F et al (2011) Nitrogen flows in farming systems across Europe. In: Sutton MA, Howard CM, Erisman JW et al (eds) European nitrogen assessment. Cambridge University Press, Cambridge, UK/New York

Jensen LS (2013) Animal manure fertiliser value, crop utilisation and soil quality impacts. Animal manure recycling: treatment and management, 295–328. http://onlinelibrary.wiley.com/doi/10.1002/9781118676677.ch15/summary

Jongema Y (2017) World list of edible insects. In: .World list of edible insects. http://www.wur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm. Accessed 28 Apr 2016

Kool A, Blonk H, Ponsioen T et al (2010) Carbon footprints of conventional and organic pork: assessments of typical production systems in the Netherlands, Denmark, England and GermanyCarbon footprints of conventional and organic pork. Blonk Milieu Advies, Gouda

Leinonen I, Williams AG, Wiseman J et al (2012) Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: broiler production systems. Poult Sci 91:8–25. https://doi.org/10.3382/ps.2011-01634

Leip A, Billen G, Garnier J et al (2015) Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environ Res Lett 10:115004. https://doi.org/10.1088/1748-9326/10/11/115004

Machovina B, Feeley KJ, Ripple WJ (2015) Biodiversity conservation: the key is reducing meat consumption. Sci Total Environ 536:419–431. https://doi.org/10.1016/j.scitotenv.2015.07.022

Mekonnen MM, Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. Ecosystems 15:401–415. https://doi.org/10.1007/s10021-011-9517-8

Menzi H, Oenema O, Burton C et al (2010) Impacts of intensive livestock production and manure management on the environment. In: Steinfeld H, Mooney H, Schneider F, Neville L (eds) Livestock in a changing landscape: drivers, consequences and responses. Island Press, Washington, DC, pp 139–163

Miglietta P, De Leo F, Ruberti M, Massari S (2015) Mealworms for food: a water footprint perspective. Water 7:6190–6203. https://doi.org/10.3390/w7116190

Murray DRP (1968) The importance of water in the normal growth of larvae of Tenebrio molitor. Entomol Exp Appl 11:149–168. https://doi.org/10.1111/j.1570-7458.1968.tb02041.x

Naylor R, Steinfeld H, Falcon W et al (2005) Losing the links between livestock and land. Science 310:1621–1622. https://doi.org/10.1126/science.1117856

Nielsen N, Jørgensen M, Bahrndorff S (2012) Greenhouse gas emission from the Danish broiler production estimated via LCA methodology. Agrotech, Arhus

Oonincx DGAB, de Boer IJM (2012) Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS One 7:e51145. https://doi.org/10.1371/journal.pone.0051145

Oonincx DGAB, van Itterbeeck J, Heetkamp MJW et al (2010) An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One 5:e14445. https://doi.org/10.1371/journal.pone.0014445

Reay DS, Davidson EA, Smith KA et al (2012) Global agriculture and nitrous oxide emissions. Nat Clim Chang 2:410–416. https://doi.org/10.1038/nclimate1458

Ripoll-Bosch R, de Boer IJM, Bernués A, Vellinga TV (2013) Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems. Agric Syst 116:60–68. https://doi.org/10.1016/j.agsy.2012.11.002

Rivera A, de la Salud Rubio M, Zanasi C, et al (2014) Environmental impact evaluation of beef production in Veracruz using life cycle assessment. In: Proceedings of the 9th international conference on life cycle assessment in the agri-food sector (LCA Food 2014), San Francisco, 8–10 Oct 2014

Robinson TP, Pozzi F (2011) Mapping supply and demand for animal-source foods to 2030. Food and Agriculture Organisation of the United Nations, Rome

Schlink AC, Nguyen ML, Viljoen GJ (2010) Water requirements for livestock production: a global perspective. Rev Sci Tech Off Int Epiz 29:603–619

Smetana S, Mathys A, Knoch A, Heinz V (2015) Meat alternatives: life cycle assessment of most known meat substitutes. Int J Life Cycle Assess 20:1254–1267. https://doi.org/10.1007/s11367-015-0931-6

Sommer SG, Hutchings NJ (2001) Ammonia emission from field applied manure and its reduction—invited paper. Eur J Agron 15:1–15. https://doi.org/10.1016/S1161-0301(01)00112-5

Sørensen P, Jensen LS (2013) Nutrient leaching and runoff from land application of animal manure and measures for reduction. In: Sommer SG, Christensen ML, Schmidt T, Jensen LS (eds) Nutrient leaching and runoff from land application of animal manure and measures for reduction. Wiley, West Sussex, pp 195–210

Steinfeld H, Gerber P, Wassenaar T et al (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome

Sutton M, Howard CM, Erisman JW et al (eds) (2011) European nitrogen assessment: sources effects and policy perspectives. Cambridge University Press, Cambridge, UK

Tilman D, Clark M (2014) Global diets link environmental sustainability and human health. Nature 515:518–522. https://doi.org/10.1038/nature13959

Winther U, Ziegler F, Skontorp Hognes E et al (2009) Carbon footprint and energy use of Norwegian seafood products. SINTEF Fisheries and Aquaculture, Trondheim

Zachariassen K (1996) The water conserving physiological compromise of desert insects. Eur J Entomol 93:359–367

Ziegler F, Winther U, Hognes ES et al (2013) The carbon footprint of Norwegian seafood products on the global seafood market. J Ind Ecol 17:103–116. https://doi.org/10.1111/j.1530-9290.2012.00485.x

Conservation of Edible Insects in Sub-Saharan Africa

Cathy Maria Dzerefos

Abstract Throughout sub-Saharan Africa wild-sourced foods, like edible insects, have been a way of life improving nutrition and providing a potential source of income. Unfortunately, natural areas are increasingly altered as time progresses through natural and anthropogenic factors that directly or indirectly alter ecosystems. Previously sacred places that were no-go areas or required special permission to access inadvertently served as havens for biodiversity. Cultural values and beliefs have informed methods of harvesting from nature. In the case of the edible stink bug *Encosternum delegorguei* some communities are focussed on short-term gains and harvest unsustainably by felling trees while others are implementing adaptive management. South Africa seems to be mindful of insect biodiversity and a few formally protected areas exist for the persistence of threatened butterflies but the inclusion of edible insects such as beetles, stinkbugs, caterpillars, locusts and termites in protected areas has historically been by accident rather than by design. As the habitat of edible insects is increasingly impacted on by human activities the benefits and potential need to be understood and managed. Community resource reserves, ecotourism and conservation flagship species for environmental education are recommended for a sustainable future.

1 Introduction

For centuries large intact expanses of wilderness have allowed for natural processes to continue and species to persist on the African continent. Threats to biodiversity conservation have escalated in recent years due to burgeoning human populations, land-use change required for infrastructure, food provision and a modern lifestyle, as well as climate change. The resultant habitat loss and fragmentation has been

C. M. Dzerefos (✉)
School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa
e-mail: cathy@dzerefos.com

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_12

Fig. 1 Dorsal view of a live specimen of *Encosternum delegorguei* (Photo credit: Mike Strever)

further exacerbated by spread of invasive alien organisms, soil erosion, environmental pollution and crop spraying (McGeoch 2002; Niba and Samways 2001). Ecosystem services such as wild-sourced foods like edible insects, are often given up in favour of formal job creation in the hope that these will develop impoverished areas. Few Environmental Impact Assessments (EIAs) which may precede conversion of wilderness areas, consider local age-old natural resource management strategies including the collection of edible insects which will be negatively impacted by the clearing of indigenous vegetation and modified ecological processes.

Entomophagy is common throughout sub-Saharan Africa (Dzerefos and Witkowski 2014) but harvesting areas have decreased in recent years. For example, traditional harvesting areas in Botswana have been converted to agriculture leading to the reduced availability of Mopane worm *Imbrasia belina* (Westwood) (Obopile and Seeletso 2013) while local extinctions of the stinkbug, *Encosternum delegorguei* Spinola have been reported in Limpopo Province, South Africa (Fig. 1; Toms and Thagwana 2003). Reduced insect harvesting has been attributed to felling of food trees for cooking and warmth (Dzerefos et al. 2009) while ecological processes have changed due to increased rate of wood harvesting in the last 20 years (Dovie et al. 2004; Twine 2005). Similarly, the felling of food trees has been suggested as a reason for reduced harvests of edible caterpillars in Nigeria (Ashiru 1988) and southern Africa (Munthali and Mughogho 1992; Akpalu et al. 2009). A study by Egan et al. (2014) in Limpopo Province, South Africa, reports that the food trees of the edible caterpillar *Hemijana variegata* Rothschild were traditionally protected by the local Induna (headman) but with modernity the authority to enforce traditional practice has dwindled. The felling of established trees to collect edible stinkbugs has also been reported in Malawi (Mlotha 2001) and South Africa (Dzerefos et al. 2013). Harvesting methods may also be changing and lead to over exploitation, for example the use of light traps can capture more insects with less effort (Ayieko et al. 2011).

1.1 Money Spinners

The caterpillar stage of *I. belina* is the most widely traded edible insect in Botswana, Namibia, South Africa and Zimbabwe (Greyling and Potgieter 2004; Obopile and Seeletso 2013) but many other insects are traded informally as food (Twine et al. 2003; Makhado et al. 2009) or are collected for household use. During the 2004/5 season (May to August) in Limpopo Province, South Africa, it was calculated that 0.1 kg dried *I. belina* fetched between US$ 0.65 to 1.30 while a cup of stinkbugs or termites fetched US$ 0.65 (Makhado et al. 2009). Out of season prices for dried *I. belina* can be higher than other sources of protein such as eggs, chicken or beef (Rebe 1999) and contributed a quarter of rural household income (Gondo et al. 2010). Similarly, the edible caterpillar *H. variegata* was more expensive than beef mince and people preferred to eat rather than sell it (Egan et al. 2014). In Zimbabwe, a study of 30 villages harvesting *E. delegorguei* showed that a household can earn US$ 190 year^{-1}, which is described as a "considerable income" for a rural area (Mapendembe 2004). A later study of 27 villages harvesting *E. delegorguei* in South Africa, found the overall harvest estimate for one season to be 3803 kg (range 0.5–13 9.2 kg household^{-1}) totalling an annual income of US$ 345 household^{-1}. Individual harvesters could earn $\overline{x}$ = US$ 746 ± 211 which was a substantial income for a rural area having a small range of income generating opportunities (Shackleton and Shackleton 2004; Dovie et al. 2005; Shackleton et al. 2008; Venter and Witkowski 2013).

1.2 Informal Conservation of Habitat and Insects

There are numerous sacred natural areas in southern Africa such as inselbergs, groupings of special trees, water sources and lakes that remain pristine due to cultural beliefs and traditions. Strong local taboos may be in place prohibiting access, killing of animals and felling of trees although some areas may be threatened by foreign commercial interests (CER 2015). Traditional rituals are required to obtain permission from the ancestors before sacred areas can be visited or altered in any way (Dzerefos et al. 2017). These sacred places have resulted in the informal conservation of biodiversity including edible insects. The Ga-Modjadji Cycad Forest and the Thate Vondo Holy forest in Limpopo Province, South Africa are two localities which have allowed for the conservation of *E. delegorguei* (Dzerefos et al. 2015). Although both sites were initially protected by local community structures, today they have formal protection through environmental legislation.

Communal-land surrounding villages, may have no-go areas where initiations into adulthood take place, during the winter holidays (July) or where traditional leaders have historically been buried. In southern Africa ancestors are revered and can reward the living as is depicted in a Shona legend from Zimbabwe which recounts how humans came to eat stinkbugs (Maredza 1987). The legend tells of

Nemeso, exiled by his father, the Induna, because he has four eyes. His fortitude is rewarded by the ancestors who show him where to find stinkbugs and render them palatable (Maredza 1987). Perhaps it is this spiritual basis that has allowed sound management of *E. delegorguei* during the harvesting season from the Jiri Forest in Zimbabwe. Each year a co-operative of 30 villages prevent tree felling, land cultivation and overexploitation through the nomination of forest monitors (Makuku 1993; Mapendembe 2004) and fines are issued for noncompliance by a community court (Mawere 2013). In the communal-lands of Limpopo Province, South African harvesters perceive the *E. delegorguei* crop to be influenced by the traditional authority retaining authority over tree felling. It is said that the crop is better in Ga-Modjadji where live trees are not felled whereas in Venda where tree felling is rife the crop has declined (Dzerefos et al. 2013). Additional methods to increase the crop of *I. belina* in communal-lands have been employed such as securing the eggs to branches with twine, protecting eggs and larvae with shade cloth, using bird deterrents, moving eggs or larvae to a better food tree, digging up the pupa and using protected pupation pits (Gardiner 2008).

1.3 Formal Conservation of Habitat and Insects

An ethnobiological survey to baseline scientific knowledge for planning, monitoring and evaluation is the starting point for formal conservation management programmes aimed at sustainable utilisation of bio-resources. Plant resources used for fuel, food, crafts, building, household utensils and medicine in southern Africa have received significantly more attention (Twine et al. 2003; Matsika et al. 2013; Venter and Witkowski 2013; Dzerefos and Witkowski 2016) than the use of animals. Ethnoentomology, the study of insects beneficial to humankind is a specialist discipline of ethnozoology. Insects receive far less research funding than iconic vertebrates such as rhinos, elephant and leopard which are also easier to observe or attach tracking devices to. Nevertheless, the few in-depth studies that do exist show insects serve an important socio-economic and ecological function in rural areas (Ashiru 1988; Greyling and Potgieter 2004; Akpalu et al. 2009; Dzerefos and Witkowski 2015). A relationship of trust is required between insect harvesters and the researcher as collection may involve trespassing or even felling of trees. Insects may be difficult to handle due to spines (Obopile and Seeletso 2013) or release of noxious chemicals (Dzerefos et al. 2009). Use of camouflage, ability to hide in crevices or suspended development in the life cycle (Dzerefos and Witkowski 2015) make research challenging. Moreover, the ability to fly allows rapid changes in distribution range across human borders and vegetation types.

The first published information on southern African insects appears to be that of Dutch explorer, author and politician, Nicolaes Witsen (1641–1717). In 1692 he published Codex Witsenii with watercolours of medicinal plants and insects from the southern Cape done by German artist Hendrik Claudius (D. McCracken, University of KwaZulu-Natal, pers. comm.). Swedish naturalist Carl Peter Thunberg (1743–1828) who is better known for botanical collections and descriptions, may have collected the first insect specimens which were taken to Europe (H. Glen, SANBI, pers. comm.).

The inclusion of edible insects such as beetles, stinkbugs, caterpillars, locusts and termites in protected areas has historically been per chance. Insect nature reserves for Red Listed or endemic butterfly species such as the Brenton Blue *Orachrysops niobe* (Trimen) and the Roodepoort Copper *Phasis dentatis* Swierstra, have been proclaimed in South Africa owing to sound environmental legislation and a body of active Lepidopterists (McGeoch et al. 2011). Currently there are no State conserved areas for edible insects in southern Africa. Even if protected areas allowed a quota of edible insects to be collected each year the management of ecological processes and protection of food plants should also be used to optimise crop yield. For example, fire is an important ecological process in savannas and timing thereof in Malawi has been shown to have a significant impact on *I. belina* yield (Munthali and Mughogho 1992).

The Kruger National Park in South Africa has since 1994 issued permits to harvesters to collect *I. belina* as part of a beneficiation and reconciliation process (Novellie et al. 2013). This is a positive development for community relationships and research data would then be available on harvest quantities and trends monitored over time to be compared to woodland fire and weather records. With the democratisation of South Africa, policies have focussed on local community's right of access. This is in line with a global trend commencing in the 1960s where protecting areas by fences and fines was replaced by the promotion of community based natural resource management systems (Cunningham 2001). In practice a combination of local governance to administer and monitor ground-rules, awareness of ecological services and participative management of communal bio-resources has worked in parts of Zimbabwe (Mutenje et al. 2011) and Lesotho (Letsela et al. 2002). The sustainable utilisation of bio-resources and the alleviation of poverty are difficult to achieve simultaneously but African case studies indicate a greater chance of success if community stewardship prevails (Mapendembe 2004; Mutenje et al. 2011).

Edible insects may also occur on private property and there are cases where *I. belina* might be managed as a commodity and landowners provide access in return for a small permit fee (Greyling and Potgieter 2004).

2 Drivers of Environmental Change in Relation to *Encosternum delegorguei*

The life history (Dzerefos et al. 2009), socio-economics (Dzerefos et al. 2014), and distribution of *E. delegorguei* (Dzerefos et al. 2015), are related to the drivers of environmental change that are operating in sub-Saharan Africa and threatening the persistence of useful savanna bio-resources. The Millennium Ecosystem Assessment defined drivers of environmental change as natural or anthropogenic factors that directly or indirectly resulted in ecosystem alteration (Nelson et al. 2005).

2.1 Local Economic Development and Land-Use Transformation

It is ironic that while the Sustainable Development Goals up to 2030 prioritise food security, an end to poverty and gender equality the natural resources which have been contributing to these goals are being eroded. Communal-lands which comprise indigenous vegetation, are not only useful for cattle and goat grazing, but also have hidden monetary streams related to bio-resource collection. As bio-resources are not part of the formal economy but occur as barter or financial transactions between individuals they are difficult to quantify. Local economics of a single edible insect species, *E. delegorguei,* have been quantified for the savanna biome and show significant monetary and nutritional value to marginalised communities (Teffo et al. 2007; Dzerefos et al. 2014). Women control 72% of the stinkbug market (Fig. 2; Dzerefos

Fig. 2 A rural woman stores *Encosternum delegorguei* in her kitchen until she has enough to sell at the urban market of Thohoyandou (Photo credit: Cathy Dzerefos)

and Witkowski 2015) which supports findings that wild sourced bio-resources provide food security and commercial opportunities for women (Shackleton and Shackleton 2004; Dovie et al. 2005; Kaschula et al. 2005; Shackleton et al. 2011). In South Africa, boys earned pocket money for clothes, sweets and cooldrinks during the school vacations by harvesting edible stinkbugs (Dzerefos et al. 2013). Children in Zimbabwe earned income from *I. belina* to pay school-fees and to purchase stationary (Gondo et al. 2010). From the onset of the harvesting season (May to August) *E. delegorguei* sells quickly by the cupful (Fig. 3) through informal markets and demand exceeds supply (Dzerefos et al. 2014). The winning formula used by Bolobedu women harvesters in South Africa is to optimise income by collecting large quantities of *E. delegorguei* and to sell quickly at relatively low prices (Dzerefos and Witkowski 2015). This strategy is employed as the women live a substantial distance from the areas where the insects are eaten. If they don't sell quickly they have to sleep overnight in friends homes, the roadside or the local police station. Since the gap between rich and poor continues to expand, wild-sourced, bio-resources should be protected for the benefit of marginalised communities.

Bio-resource contribution to socio-economic stability (Paumgarten 2005; van Huis 2013) should be fully reported on through specialist studies in the EIA process. In South Africa, EIAs are regulated by the National Environmental Management

Fig. 3 A young man with live *Encosternum delegorguei*, held in a bag previously used for citrus. He is holding an enamel cup which will be used to measure and sell the insects (Photo credit: Cathy Dzerefos)

Act (NEMA) (Act 107 of 1998) since land-use change may impact on species of special concern or livelihoods of bio-resource harvesters (Dzerefos and Witkowski 2016). Bio-resource collection should be considered as an alternative economic development model before irreversible decisions to change land-use of a rural area are taken. Currently EIAs do not quantify the value of bio-resources to communities and only medicinal plants or endemic and threatened invertebrates are occasionally considered (McGeoch et al. 2011). Due to expanding human population and requirements for planted crops, housing and work opportunities in sub-Saharan Africa key drivers of environmental change are local economic development and land-use transformation.

In South Africa, Ezemvelo KZN Wildlife, the conservation authority of KwaZulu Natal Province, is a role model for insect conservation. Distribution records for 3649 invertebrates have been collected which can be consulted when land-use change is being considered (McGeoch et al. 2011). The proposed land-use transformation could be halted or mitigation measures to reduce the impacts could be put into place (McGeoch et al. 2011) such as the rerouting of a road due to the presence of the Karkloof Blue butterfly *Orachrysops ariadne* (Butler) (McGeoch et al. 2009).

2.2 Cultural Values and Beliefs

Cultural values and beliefs drive actions such as methods of harvesting and determine whether a community is focussed on short-term gains or consider long-term impacts and holistic approaches such as biodiversity stewardship, adaptive management and ecotourism developments which support sustainable harvesting. As the distribution of *E. delegorguei* and its most efficient predator, humans, increasingly overlap, the interaction needs to be understood and used for mutual benefit (Dzerefos and Witkowski 2015). For example, conservation strategies for medicinal plants and the ecosystems in which they are found (Madimetja et al. 2010) or husbandry of *I. belina* to increase yield (Gardiner 2008).

Apart from traditional food use another angle to improve rural livelihoods using *E. delegorguei* would be to latch onto the growing public interest in insects, and offer stinkbug harvesting and processing tours. The diamond mining multinational De Beers "Biodiversity is forever" publicity campaign of 2008/9 is one example where insects have been used as iconic environmental best practice indicators. Furthermore, the "Yebo Gogga Yebo amaBlomo" annual exhibition at the University of the Witwatersrand for schools and restaurant menus in Johannesburg (Fig. 4) indicate a growing interest in tasting edible insects. Establishment and persistence of butterfly reserves and farms as well as a dragonfly trail (Niba and Samways 2001) suggest that invertebrates are gaining popularity and interest.

Education for sustainable development also has a role to influence values and beliefs as these are not static. Resources have been developed for teachers to use in the classroom on insects and sustainable use. For example, WESSA, the Wildlife

Fig. 4 The Holiday Inn at OR Tambo International Airport serves a salad and canapes with crunchy flavourful *Imbrasia belina* (Photo credit: Cathy Dzerefos)

and Environment Society of South Africa, devoted an entire volume of EnviroKids to insects (Griffiths 2016) and the Feline Fields Trust in Maun, Botswana, has developed an information booklet and quiz to engage children in the conservation of *I. belina* and termites (Feline Fields Trust 2016). Various efforts have been taken to raise the profile of insects at the community level for example Ezemvelo KZN Wildlife on the Karkloof Blue butterfly (McGeoch et al. 2009) and the Friends of the Haenertsburg Grassland on insect diversity (Dzerefos and Witkowski 2016).

There are two dominant value systems with regards to stinkbugs that have an environmental impact (Dzerefos and Witkowski 2015). Firstly, harvesters and consumers consider *E. delegorguei* a tasty traditional food and impact through direct exploitation of winter aggregates. They are amenable to an adaptive management system that would result in persistence of the insect for continued exploitation. Secondly a larger group of people who do not eat stinkbugs, perceive *E. delegorguei* only as a pest and use derogatory names such as stinkbug or "podile" meaning "it is rotten" (Dzerefos et al. 2013). These non-eaters impact indirectly on *E. delegorguei* by altering land-use or felling food trees. Both eaters and non-eaters could be mobilised through an awareness campaign to extend insect and habitat conservation beyond the fences of protected areas (Niba and Samways 2001) and into private gardens and communal-lands where *E. delegorguei* may be using trees to oviposit and feed. Monitoring of woody vegetation composition in communal-lands in southern Africa shows radical change due to anthropogenic activity (Matsika et al. 2013; Mograbi et al. 2015). These changes suggest that tree planting initiatives and methods promoting coppice (Luoga et al. 2004) have a major role in woodland regeneration. Choices of trees to plant could be related to the beneficial insects of a locale. For example, Dzerefos et al. (2009) found that *Combretum imberbe* Wawra, *Combretum molle* R.Br. ex G. Don, *Peltophorum africanum* Sond., as well as the shrub *Dodonaea viscosa* Jacq. var. *angustifolia* (L.f.) Benth were food plants for *E. delegorguei* while Makhado et al. (2009) identified *Colophospermum mopane* (J.Kirk ex Benth.) J.Kirk ex J.Léonard as the primary food source for *I. belina*.

The consumption of edible insects such as *E. delegorguei* and *I. belina* are unlikely to decrease with the rise of modernity since they are not shunned by the growing middle class. In the last 30 years, the Bolobedu people who previously did not know about *E. delegorguei*, have started harvesting and preparing *E. delegorguei* from their land and selling the processed crop to Vhavenda people who consider this insect a delicacy (Dzerefos et al. 2013). The past and present value of *E. delegorguei* was highlighted in a Zimbabwean newspaper report where the chief of Nerumedzo village proudly proclaimed: "Harurwa is gold here. They were used to pay our mothers' lobola (bride price)" (NewsDay 2010).

Harvesters are known to travel up to 200 km to collect *E. delegorguei* for direct consumption and trade (Dzerefos et al. 2014) during its winter aggregation (Fig. 5). Climbing trees or hooking and pulling down branches were sustainable harvesting methods commonly employed for collecting stinkbugs but occasionally branches may be cut or were accidentally broken (Dzerefos et al. 2013). It is of growing

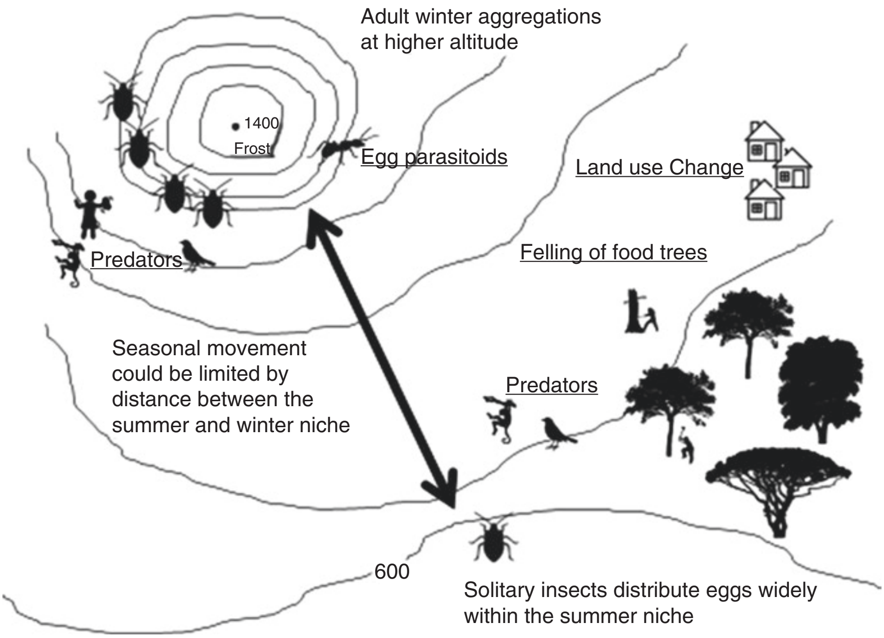


Fig. 5 Schematic representation of *Encosternum delegorguei* seasonal migration which is a challenge to systematic conservation plans. Threats to the insect crop have been underlined

concern that in forest plantations and private land, where access is not permitted, poachers damage growing points of young pines and fell mature trees to access stinkbugs. It is important that harvesting in these areas is legitimised to allow monitoring and the introduction of a collection funnel (Dudley 2004) as an alternative to felling trees.

2.3 Climate Change, Biodiversity and Ecosystem Services

Insect species have been shown to reduce, expand or shift current ranges due to climate change with the worst-case scenario being extinction. For South Africa, the future impact of climate change on biodiversity and ecosystem services has been predicted through distribution modelling (DEA 2013), while a national adaptation strategy is being developed to mitigate impacts on food security and human health. In Botswana, the semi-arid climate prevents the residents from being able to grow their own food and formalisation of sustainable use of natural resources to supplement nutrition is being researched by government (Obopile and Seeletso 2013).

The current and future distribution of *E. delegorguei* has been predicted using a maximum entropy modelling method (MAXENT) in South Africa and to a lesser extent in Zimbabwe and Malawi. Protected areas could be considered in areas of overlap since other factors such as elevation, distance to feeding grounds or parasitoid threat could prevent colonisation of new areas (Dzerefos et al. 2015). The results also provide a robust baseline measure, with an AUC (area under the curve) value of 0.995, upon which the modelled predictions can be evaluated and monitored.

Climate change may affect the summer and the winter niches of *E. delegorguei* (Fig. 5). Winter physiological changes observed in *E. delegorguei* included change of colour, increased abdominal fat content and wax secretions (Dzerefos et al. 2009). These changes indicate diapause or suspended development during a time when environmental conditions were sub-optimal (Musolin et al. 2007). The physiological response concurs with the results of the *E. delegorguei* MAXENT distribution model which identified winter precipitation as the most influential climatic variable (Dzerefos et al. 2015). To a lesser degree summer precipitation and temperature also limit distribution. Dzerefos et al. (2009), established that during winter *E. delegorguei* requires condensed water to drink although it is not feeding off plants at this time of year. Hence, *E. delegorguei* has temporal food requirements which are spatially and seasonally distinct (Fig. 5). Winter locations ranged from 597 to 1147 m altitude in valleys and hollows of escarpment foot slopes. During winter *E. delegorguei* uses a range of indigenous tree and shrub species as well as exotic fruit and timber trees as perches. Following copulation in spring (September) females search and feed on the trees *Combretum imberbe, Combretum molle* and *Peltophorum africanum* and to a lesser degree on the shrub *Dodonaea viscosa*. These woody plants occur in low altitude vegetation where they are communal sources of fuel and building materials for local communities (Anthony and Bellinger 2007). Trees constitute the primary fuel source of over 70% of sub-Saharan Africans

(Matsika et al. 2013) and their exploitation may influence the food available for *E. delegorguei.* Food trees should be further investigated and monitored as an important categorical variable limiting distribution. Fortunately, being a generalist feeder there may be a range of plants, including coppiced tree or shrub stumps, resulting from responsible wood harvesting, which could be used. The widespread spring dispersal may serve to minimize egg parasitoids locating *E. delegorguei* eggs.

Climate change may influence phenology such that the leafless period of food trees is synchronised to late rainfall but may be unsynchronised to eclosion. Furthermore, if occurrence and frequency of the mist-belt is altered with climate change the availability of vapour condensation during the winter may affect survival. Future distribution predictions have been made according to the bioclimatic envelope of *E. delegorguei*. Successful migration requires that insects have sufficient fat reserves to reach wintering sites, survive the diapause period and return successfully to feeding grounds (Alerstam et al. 2003). Predictions indicate that the current *E. delegorguei* distribution could shift by 16% westwards and southwards particularly along the southern margin of the current range in Mpumalanga Province, South Africa (Dzerefos et al. 2015).

3 Conclusions

Traditionally local natural resource management strategies were controlled by the local traditional authority or Induna but these are weakening over time and need to be replaced by formal national strategies that are linked to environmental legislation and community buy-in (Dzerefos and Witkowski 2016). Seldom are useful species such as *E. delegorguei* promoted within communities as a conservation flagship species (Bowen-Jones and Entwistle 2002). Instead flagship species tend to appeal to foreign donors but to local communities they might be nuisance animals preying on livestock, or raiding crops. The provincial authorities have departments for environmental education and biodiversity protection that should promote flagship species awareness and conservation within communities. Provincial conservation authorities working with communities could also engage in local mini-livestock production, diversifying products being produced or adding value to the current product with possible worldwide distribution. New localities could be sought to increase the harvest or community resource nature reserves could be proclaimed and managed for ecological services. In addition, the provincial authorities should not approve EIAs, that is a legal requirement for land-use change, which have not considered the loss of bio-resources to communities or the potential expansion of markets.

Empowerment of communities to be adaptive managers that monitor threats and instigate corrective action to maintain ecological services (Table 1; Fabricius et al. 2007) should be a goal that provincial conservation authorities in collaboration with traditional authorities are striving towards. Specific short-term goals could be to establish no-go areas and woodland monitors to ensure trees are not felled or at least

Table 1 Recommendations for protecting savanna biome biodiversity with *Encosternum delegorguei* as a flagship species for *in situ* conservation

Threats	Possible solution
Over exploitation of ecosystem or species by local communities.	An adaptive management plan for the ecosystem with local community involvement.
Over exploitation of ecosystem or species by third parties offering economic growth.	Applications to include bio-resource income generation and loss before provincial conservation authorities give authorisation.
Pesticide use on macadamia and mango farms, tea and pine plantations adjoining aggregation sites.	Integrated pest management to monitor pests and apply pesticides manually not through crop spraying. Farmers should be aware that *E. delegorguei* is not a pest as it does not feed in winter and has a short proboscis.
Environmental requirements of local people such as jobs, food security, water, grazing and bio-resources are challenging to realise.	Optimise economic benefits from *E. delegorguei*, exercise control over fire regime, cattle carrying capacity and use of fuel trees. Diversify income streams through ecotourism.
Poor returns for huge effort.	Increase overall productivity as a termiticide or hangover or common cold medicine to accrue increased economic benefits for harvesters.
Reduce the use of fuelwood.	Introduce stoves, hay boxes or insulation of fire and pot with a clay wall to reduce amount of wood being used. Promote coal-generated power and alternative energy to rural areas (Wessels et al. 2013).
Practice sustainable methods of fuelwood harvesting.	Promote indigenous tree planting within the summer niche at homesteads, schools and along roads to secure the food source. The felling of trees should be done at the optimal time, leaving a stump that is most likely to coppice (Luoga et al. 2004). This may need to be protected from grazing goats by making a fence around the stump with thorn branches or overlaying bricks.
Unknown and unregulated poaching from protected areas, private farms and plantations.	Allow harvesters access to harvest sustainably and introduce the use of a collecting funnel to discourage felling of trees (Dzerefos et al. 2013).
Rising transport and accommodation costs and selling at discounted prices.	Form cooperatives as a means of mercantile production to assist each other with sales and avoid middlemen. Set up customer database to inform of availability using cellular networks.
Expanding human populations and increasing need for food.	Mini-livestock production under optimal conditions could increase growth rate or generation time such that the edible harvestable period is prolonged.
E. delegorguei is unknown and labelled as rotten by some.	Increase knowledge and appreciation of *E. delegorguei* by dissemination of information through inclusion in the national school curriculum, talks on local radio stations and posters or flyers in local languages.
Entomophagy is not appreciated by most people.	Implement national education for sustainable development strategy.
Climate change is altering the distribution of biodiversity at an unknown spatio-temporal scale.	Monitor the predicted current and future distribution in relation to the MAXENT model produced (Dzerefos et al. 2015).

able to coppice after harvesting, prevent fires or close the harvesting season when copulation commences. Medium-term goals could consider harvesting quotas or fees. A harvesting fee could possibly be used to purchase feed and negate the need to burn dormant vegetation to provide winter cattle-grazing. The implementation of such actions could be evaluated and improved over time.

The conservation of insects requires management of habitat (McGeoch 2002) but very little formal conservation is being done for edible insects in southern Africa. Complexities that would need to be considered are fragmentation, succession, fringe effects and resilience of the ecosystem to climate change. Failure to manage the habitat or introduce a sustainable harvesting regime would necessitate costly species management or mini-livestock production to prevent extinction and loss of food security in impoverished areas.

References

Akpalu W, Muchapondwa E, Zikhali P (2009) Can the restrictive harvest period policy conserve Mopane worms in southern Africa? A bioeconomic modelling approach. Environ Dev Econ 14(5):587–600

Alerstam T, Hedenström A, Åkesson S (2003) Long-distance migration: evolution and determinants. Oikos 103(2):247–260

Anthony BP, Bellinger EG (2007) Importance value of landscapes, flora and fauna to Tsonga communities in the rural areas of Limpopo Province, South Africa. S Afri J Sci 103:148–154

Ashiru MO (1988) The food value of the larvae of *Anaphe venata* Butler (Lepidoptera: Notodontidae). Ecol Food Nutri 22:313–320

Ayieko MA, Obonyo GO, Odhiambo JA et al (2011) Constructing and using a light trap harvester: rural technology for mass collection of Agoro termites (*Macrotermes subhylanus*). Res J Appl Sci Eng Technol 3(2):105–109

Bowen-Jones E, Entwistle A (2002) Identifying appropriate flagship species: the importance of culture and local contexts. Oryx 36:189–195

Centre for Environmental Rights (CER) (2015) Traditional healers lay criminal charges against mining company and its directors for environmental crimes. www.cer.org.za/news/traditional-healers-lay-criminal-charges-against-mining-company-and-its-directors-for-environmental-crimes. Accessed 3 Dec 2015

Cunningham AB (2001) Applied ethnobotany: people, wild plant use and conservation. Earthscan, London

Department of Environmental Affairs (DEA) (2013) Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. https://www.environment.gov.za/sites/default/files/docs/summary_policymakers_bookV3.pdf. Accessed 26 January 2018

Dovie DBK, Witkowski ETF, Shackleton CM (2004) The fuelwood crisis in southern Africa–relating fuelwood use to livelihoods in a rural village. GeoJournal 60:123–133

Dovie DBK, Witkowski ETF, Shackleton CM (2005) Monetary valuation of livelihoods for understanding the composition and complexity of rural households. Agric Hum Values 22:87–103

Dudley CO (2004) Management of biodiversity in protected areas of Malawi. National Herbarium and Botanic Gardens, Zomba, Malawi. Document Reference PN93-22082-06-208 and PN 00.2047.9-002.13

Dzerefos CM, Witkowski ETF, Toms R (2009) Life-history traits of the edible stinkbug, *Encosternum delegorguei* (Hem., Tessaratomidae), a traditional food in southern Africa. J Appl Entomol 133:749–759

Dzerefos CM, Witkowski ETF, Toms R (2013) Comparative ethnoentomology of stinkbug use in southern Africa and sustainable management considerations. J Ethnobiol Ethnomed 9:20. www.ethnobiomed.com/content/9/1/20. Accessed 1 Dec 2016

Dzerefos CM, Witkowski ETF, Toms R (2014) Use of the stinkbug, *Encosternum delegorguei* (Hem., Tessaratomidae) for food and income in South Africa. Soc Nat Resour 27(8):882–897

Dzerefos CM, Witkowski ETF (2014) The potential of entomophagy and the use of the stinkbug, *Encosternum delegorguei* Spinola (Hem., Tessaratomidae) in sub-Saharan Africa. Afri Entomol 22(3):461–472

Dzerefos CM, Erasmus BFN, Witkowski ETF et al (2015) Modelling the current and future dry-season distribution of the edible stinkbug *Encosternum delegorguei* in sub-Saharan Africa. Entomol Exp Appl 156:1–13. https://doi.org/10.1111/eea.12309

Dzerefos CM, Witkowski ETF (2015) Crunchtime: sub-Saharan stinkbugs, a dry season delicacy and cash cow for impoverished rural communities. Food Secur 7(4):919–925. https://doi.org/10.1007/s12571-015-0479-0

Dzerefos CM, Witkowski ETF (2016) Bridging the knowing-doing gap in South Africa and the role of environmental volunteer groups. Koedoe 58. https://doi.org/10.4102/koedoe.v58i1.1394

Dzerefos CM, Witkowski ETF, Kremer-Köhne S (2017) Aiming for the biodiversity target with the social welfare arrow: medicinal and other useful plants from a Critically Endangered grassland ecosystem, Limpopo Province, South Africa. Int J Sustain Dev World Ecol 24(1):52–64. https://doi.org/10.1080/13504509.2016.1174963

Egan BA, Toms R, Minter LR et al (2014) Nutritional significance of the edible insect, *Hemijana variegata* Rothschild (Lepidoptera: Eupterotidae), of the Blouberg Region, Limpopo, South Africa. Afri Entomol 22:15–23

Feline Fields Trust (2016) http://felinefields.com/conservation/. Accessed 1 Dec 2016

Fabricius C, Folke C, Cundill G et al (2007) Powerless spectators, coping actors, and adaptive co-managers: a synthesis of the role of communities in ecosystem management. Ecol Soc 12(1):29. www.ecologyandsociety.org/vol12/iss1/art29/. Accessed 1 Dec 2016

Gardiner AJ (2008) Mopane worm farming a guide. Department for International Development, United Kingdom. ISBN13: 978-1-904289-48-7

Gondo T, Frost P, Kozanayi W et al (2010) Linking knowledge and practice: assessing options for sustainable use of Mopane worms (*Imbrasia belina*) in southern Zimbabwe. J Sustain Dev Afri 12(4):127–145

Greyling M, Potgieter M (2004) Mopane worms as a key woodland resource. In: Lawes MJ, Eeley HAC, Shackleton CM et al (eds) Indigenous forests and woodlands in South Africa. University of Kwazulu-Natal Press, Pietermaritzburg, pp 575–589

Griffiths R (2016) Insects in our lives. EnviroKids 32(2):3–17

Kaschula SA, Twine WE, Scholes MC (2005) Coppice harvesting of fuelwood species on a South African common: utilizing scientific and indigenous knowledge in community based natural resour management. Hum Ecol 33(3):387–418

Letsela T, Witkowski ETF, Balkwill K (2002) Direct use values of communal resources in Bokong and Tsehlanyane in Lesotho: whither the commons? Int J Sustain Dev World Ecol 9:351–368

Luoga EJ, Witkowski ETF, Balkwill K (2004) Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land-use. Forest Ecol Manag 189:23–35

Madimetja DM, Masoga MA, Mearns MA (2010) Traditional health practitioners' practices and the sustainability of extinction-prone traditional medicinal plants. Int J Afri Renaiss Stud 5(2):229–241. https://doi.org/10.1080/18186874.2010.534842

Makhado RA, von Maltitz GP, Potgieter MJ, Wessels DC (2009) Contribution of woodland products to rural livelihoods in the northeast of Limpopo Province, South Africa. S Afri Geogr J 91(1):46–53

Makuku SJ (1993) Community approaches in managing common property forest resources: the case study of Norumedzo community in Bikita. In: Piearce GD, Gumbo DJ (eds) Proceedings of an international symposium on ecology and management of indigenous forests in southern Africa. Zimbabwe Forestry Commission, Victoria Falls, pp 86–96

Mapendembe A (2004) The role of non-timber forest products in forest conservation and rural livelihoods: the case of the edible stinkbug (*Encosternum delegorguei*) in ward 15 of Bikita District, Zimbabwe. PhD thesis, University of Zimbabwe, Zimbabwe

Maredza C (1987) Harurwa. Longman, Harare

Matsika R, Erasmus BFN, Twine W (2013) Double jeopardy: the dichotomy of fuelwood use in rural South Africa. Energy Policy 52:716–725

Mawere M (2013) A critical review of environmental conservation in Zimbabwe. Afri Spectr 48(2):85–97. http://journals.sub.uni-hamburg.de/giga/files/journals/1/articles/650/public/650-675-1-PB.pdf. Accessed 1 Dec 2016

McGeoch MA (2002) Insect conservation in South Africa. Afri Entomol 10(1):1–10

McGeoch MA, Samways MJ, New TR (2009) Insect conservation: a handbook of approaches and methods. Oxford University Press, London, p 370

McGeoch MA, Sithole H, Samways MJ et al (2011) Conservation and monitoring of invertebrates in terrestrial protected areas. Koedoe 53(2). https://doi.org/10.4102/koedoe.v53i2.1000

Mlotha MJ (2001) Remote sensing and GIS linked to socio-analysis for land cover change assessment. In: Abstracts of the proceedings of the geoscience remote sensing symposium, University of New South Wales, Sydney, 9–7 July

Mograbi PJ, Erasmus BFN, Witkowski ETF et al (2015) Biomass increases go under cover: woody vegetation dynamics in South African rangelands. PLoS One 10(5). https://doi.org/10.1371/journal.pone.0127093

Munthali SM, Mughogho DEC (1992) Economic incentives for conservation: bee keeping and Saturniidae caterpillar utilisation by rural communities. Biodivers Conserv 1:143–154

Musolin D, Fujisaki K, Numata H (2007) Photoperiodic control of diapause termination, colour change and postdiapause reproduction in the Southern green stinkbug, *Nezara viridula*. Physiol Entomol 32(1):64–72

Mutenje MJ, Ortmann GF, Ferrer SRD (2011) Management of non-timber forestry products extraction: local institutions, ecological knowledge and market structure in South-Eastern Zimbabwe. Ecol Econ 70:454–461

Niba A, Samways MJ (2001) Development of a dragonfly awareness trail in an African botanical garden Biological Conservation 100(3):345–353

Nelson GC, Bennett WE, Berhe AA et al (2005) Socio-economic transitions influence vegetation change in the communal rangelands of the South African rangelands. Afri J Range Forage Sci 22(2):93–99

Newsday (2010) Harurwa – more than food in Bikita. www.newsday.co.zw/2010/09/07/2010-09-07-harurwa-more-than-food-in-bikita/. Accessed 26 January 2018

Novellie P, Biggs H, Freitag-Ronaldson S (2013) Research and monitoring: interface with legislation, policy and management. SANParks, South Africa. www.sanparks.org/assets/docs/conservation/reports/2013_research_report.pdf. Accessed 26 January 2018

Obopile M, Seeletso TG (2013) Eat or not eat: an analysis of the status of entomophagy in Botswana. Food Security 5(6):817–824

Paumgarten F (2005) The Role of non-timber forest products as safety-nets: A review of evidence with a focus on South Africa. GeoJournal 64(3):189–197

Rebe M (1999) The sustainable use of Mopane worms as a harvestable protein source for human consumption: local perceptions. MSc thesis. University of Pretoria, South Africa

Shackleton CM, Shackleton SE (2004) The importance of non-timber forest products in rural livelihood security and as safety nets: a review of evidence from South Africa. S. Afri. J. Sci. 100:658–664

Shackleton S, Campbell B, Lotz-Sisitka H, Shackleton C (2008) Links between the Local Trade in Natural Products, Livelihoods and Poverty Alleviation in a Semi-arid Region of South Africa. World Development 36(3):505–526

Shackleton S, Paumgarten F, Kassa H, Husselman M, Zida M (2011) Opportunities for enhancing poor women's socioeconomic empowerment in the value chains of three African non-timber forest products (NTFPs). International Forestry Review 13(2):136–151

Teffo LS, Toms RB, Eloff JN (2007) Preliminary data on the nutritional composition of the edible stinkbug, Encosternum delegorguei Spinola, consumed in Limpopo Province, South Africa. S. Afr. J. Sci. 103:434–436

Toms RB, Thagwana MP (2003) Eat your bugs! http://www.scienceinafrica.co.za/2003/october/stinkbug.htm. Accessed 12 Aug 2013

Twine WC, (2005) Socio-economic transitions influence vegetation change in the communal rangelands of the South African lowveld. African Journal of Range & Forage Science 22(2):93–99

Twine WD, Moshe T, Netshiluvhi TR, Siphugu V (2003) Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo Province, South Africa. S Afri J Sci 99:467–473

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

Venter S, Witkowski ETF (2013) Fruits of our labour: contribution of commercial baobab (*Adansonia digitata* L.) fruit harvesting to the livelihoods of marginalized people in northern Venda, South Africa. Agrofor Syst 87:159–172

Wessels KJ, Colgan MS, Erasmus BFN, Asner GP, Twine WC, Mathieu R, van Aardt JAN, Fisher JT, Smit IPJ (2013) Unsustainable fuelwood extraction from South African savannas. Environmental Research Letters 8(1):014007

Sustainable Proteins? Values Related to Insects in Food Systems

Christian Gamborg, Helena Röcklinsberg, and Mickey Gjerris

Abstract Developing large scale production systems for farmed insects to supplement or replace feed and food ingredients from vertebrate livestock is often heralded as a more sustainable way to produce animal protein than currently used livestock production methods and is receiving increased interest from a diverse set of stakeholders ranging from political decision makers, environmental interest groups, farmers, industry and scientists. This is hardly a surprise, as sustainability has been widely embraced as a broad and inclusive political (ideological) as well as managerial (practical) framework. Ideally sustainability is a balance between a one-sided focus on productivity and profit on the one hand, and uncompromising demands for nature preservation and calls for radical changes in the agricultural production on the other. But there are different views on how to strike that balance – to some extent reflecting different values – which in turn gives rise to different challenges on how insects can contribute to food systems around the world.

1 Introduction: Why Insects for Food and Feed?

Sustainability – in its broadest sense encompassing environmental, economic and social dimensions – is widely embraced as a broad and inclusive ethical as well as managerial framework allowing for a common platform for discussing productivity and nature related concerns in many, if not all sectors of society, including food and feed production (Gamborg and Sandøe 2005). In this chapter we present an account of the values related to insects in food systems, discussing mainly concerns related to the environmental dimensions of sustainability that producing insects for food

C. Gamborg (✉) · M. Gjerris
Department of Food and Resource Economics, University of Copenhagen, Copenhagen, Denmark
e-mail: chg@ifro.ku.dk

H. Röcklinsberg
Department of Animal Environment and Health, Swedish University of Agricultural Sciences, Uppsala, Sweden

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_13

and animal feed may give rise to. In doing this we draw the attention to a wider set of values and ethical issues related to insect production, including issues related to animal welfare and wider animal ethical issues. It should be noted that both insect production and other kinds of protein production, whether based on plants or animals, differ a lot both with regard to intensiveness/extensiveness, size, environmental impact etc. In this chapter we discuss the general issues related to claims about sustainability, but fully acknowledge that it is necessary to be much more specific than we are able to be here to make an actual comparison of the different systems.

For many years global food security – understood as the task of providing an adequate and nourishing diet for all humans – has been high on the global agenda (FAO 2015a). Despite intensive efforts there are still almost 800 million people, mostly in the developing world, who do not have enough food to live a healthy active life (FAO 2015b). It is estimated that more than three million children under the age of 5 die every year because of poor nutrition (The Lancet 2013). The second of the 17 *Sustainable Development Goals* of the United Nations that officially came into force in 2016 states that the global community should work to eradicate hunger by the year 2030 (United Nations 2015).

This food security challenge hence has two interacting dimensions. One is the actual population growth, the other is a potential shift to animal based protein in regions so far eating a plant based diet. As showed by FAO, in e.g. India and South Asia demand for poultry meat will increase also independently of population growth with about 725–850% the coming 30 years (FAO 2011). The severity of the situation is visible by a number of further facts: (i) A growing world population estimated to reach 8.5 billion in 2030, 9.7 billion in 2050 and 11.2 billion in 2100 (United Nations 2015); (ii): The subsequent need to increase food production, both to allow for a growing population and a shift towards a diet containing more animal protein in many parts of the world, resulting in a need to increase global food production by 60% by 2050 (Alexandratos and Bruinsma 2012); and (iii): Climate change is expected to create difficulties for global food production through both direct and indirect effects, which increases the need to develop a "climate-smart food system" to ensure food security for a growing world population (Wheeler and von Braun 2013), including ensuring that produced food is actually consumed by reducing food waste (Sala et al. 2017).

On top of these challenges comes the growing acknowledgement that current food production systems, especially animal production systems, are at odds with the idea of a sustainable food production (Röös et al. 2016). Conventional livestock production such as cattle affects its surroundings substantially (Gamborg and Gjerris 2012; Ilea 2009). About 2/3 of all arable land is already used for animal production which has been shown to contribute to deforestation, changes in savannas, drainage of wetlands, and desertification (Norris et al. 2010). In general, current livestock production is a cause of environmental degradation in many cases (Steinfeld et al. 2013). Furthermore, the livestock sector is a significant contributor to GHG emissions that creates climate change that subsequently will create further challenges to food production as mentioned above. The contribution of the livestock sector to anthropogenic GHG emissions is estimated as ranging from 14.5%

(Gerber et al. 2013) to 18% (Steinfeld et al. 2006) to more than 50% (Goodland and Anhang 2009). A consequence of this is that just securing the necessary feed resources to a growing population demanding animal protein on a daily basis while at the same time attempting to lessen the environmental and climate impact will be one of the most challenging issues for ordinary livestock production (Makkar et al. 2014) and for aquaculture (Henry et al. 2015) in the future.

The search for solutions to the combined challenges described above has led some researchers to suggest that utilizing insects as a source for food and feed through the development of efficient large-scale production systems could be a significant factor in both ensuring food security (van Huis et al. 2013) and developing a more sustainable food production (Oonincx et al. 2010). In the following sections we will look more closely at why insects for food and feed in the rapidly growing literature are considered more sustainable than current production systems – recognising the multitude of different systems and possible insect production systems – beginning with a discussion of what sustainability may entail.

2 Sustainability: A Complicated Concept with Ethical Implications

The notion of sustainability, although notoriously unclear, has escalated as a contemporary concern (Nel and Ward 2015). It is seen as a fundamental principle which influences or even transforms governance (Bosselmann 2016). Originally, the concept was tied to long-term and wise management of natural resources such as forestry and fishery – then often referred to as 'sustained yield' serving the purpose of procuring certain goods (Gamborg and Larsen 2005) – but during the last 250 years, the interpretation of sustainability has evolved and today it is used as a comprehensive concept integrating ecological, economic and social aspects of the use of the natural environment and development of society. As such, sustainability is widely embraced as common platform for discussing productivity and nature related concerns in many, if not all sectors of society, including food and feed production (Gamborg and Sandøe 2005).

From an economical perspective sustainability is often seen as a question of determining the short and long term gains from different activities and include discussions of to what extent certain resources are renewable or considered replaceable, and at what cost. From a social perspective sustainability is often seen as an ethical demand to create a fairer international and intergenerational resource distribution, often coupled with notions such as worker's rights, public involvement and inclusion of animals in the ethical sphere. From an environmental perspective the focus is on the effects of human activities on ecosystems and biodiversity, often coupled to questions about the regenerative capacity of natural systems. However, the precise relevance and content of the different aspects of the concept are understood very differently in the vast literature as different interpretations in relation to the various aspects of sustainability spanning from business as usual, over modernization, to radical change (Söderbaum 2014).

The concept's ethical thrust is toward social justice and future generations. But, as mentioned above, it can also be used as a concept espousing the moral relationship between human beings, animals and the natural environment. As such the concept of sustainability also includes ethical considerations on which kinds of beings have moral standing; That is, what beings should be considered morally significant and seen as part of a moral community encompassing moral agents (some humans) and moral patients (all humans and perhaps animals and other organisms)? Very roughly, three types of theory can be distinguished on the question whether we have responsibilities to or regarding animals and the natural environment?

The first view, an anthropocentric or human-centred ethics, holds that responsibilities, if any, towards animals or other parts of nature derives entirely from human interests. Any responsibility regarding animals and the natural environment are thus indirect. This view can be extended so that *future* human generations are also objects of moral responsibility. Much of the concern about future generations that is visible in most commonly held views on sustainable development can be explained in anthropocentric terms. Thus, concerns about insects used for food and feed are not directly related to insects themselves or the environment of which they are part, should according to this human-centred perspective solely be evaluated in relation to the effects such a use of insects would have in terms of positive or negative consequences for humans, e.g. in terms of food security, nutritional value, and economic and environmental impact.

According to the second ethical view called sentientism that belongs to the group of non-anthropocentric views on moral standing, all beings – humans or not – who are capable of having subjective experiences of pain and pleasure in such a way that their welfare matters to them, are directly ethically relevant. This view can be found in both utilitarian and rights-based versions, and states that all sentient animals are to be included into the moral community and their interests taken into consideration when evaluating the ethical acceptability of a given action. With regard to insects used as food and feed, consequences for sentient animals ought therefore to be included in the ethical consideration in line with considerations for humans, both living and future. From this perspective it becomes very important whether insects are considered to be sentient or not. Today the mainstream scientific view is that insects are not capable of experiencing individual welfare or sentient enough to be granted legal protection as e.g. mammals.

The question of "insect welfare" is however attracting increasing interest these years as the interest to utilize insects in large scale production systems to produce protein for food and feed is growing. With more than one million species of insects, of which approximately 2000 at the moment are used for food purposes (Jongema 2015), and with huge differences between them this question cannot be answered in general. Although comparisons and analogies can be made between different species, the potential for welfare experiences needs to be answered for the species in question. Further, if they do have the capacity for welfare, an understanding of how to design production systems to avoid impairment of their welfare needs to be developed, given they are considered worthy of ethical consideration. So far the empirical evidence for insect welfare is weak. According to a review by Eisemann et al. (1984: 166): "*the neural organization of insects and observations of their behaviour does not appear to support the occurrence in insects of a pain state, such as occurs in humans*". The same conclusion was reached in another, more recent study that found that little neurobiological evidence seemingly exists for the existence of pain-like states in insects (Sneddon et al. 2014). A further problem is that it can be very hard to determine whether insects can experience welfare as they are so different to us compared to e.g. mammals. As Smith (1991: 30) notes: *"The question of pain in invertebrates will be very difficult to resolve - if, indeed, it is resolvable*".

Some researchers are, however, more open to the idea of at least some insects having the capacity for welfare. According to Broom (2001) there is evidence for some aspects of pain in invertebrates, but as he himself points out in a later work: "[*t]he more different from humans an animal appears to be, the less likely it is to be evaluated as sentient*" (Broom 2014: 66). There are, however, other more recent studies that show that nociception and the capacity to integrate information into complex decisions are present in at least some invertebrates (e.g. honey bees and spiders) (Elwood 2011) which opens the possibility of insect welfare being a meaningful concept, at least within some species. Sherwin (2001) cites several studies pointing to both physiological and behavioural evidence that pain perception does exist in insects. On this basis, she argues that if we accept the "argument-by-analogy" when assigning e.g. a chimpanzee the ability to feel pain when receiving an electric shock – because we recognize the similarity with our own reaction – we should be willing to do the same with insects, when we discover that they have mental abilities that are analogous to those of beings who we accept as experiencing pain. From a sentientistic viewpoint this question is crucial for the development of large scale production systems. If the relevant insect species have the ability to experience welfare, the ethical acceptability of using insects for food and feed, hinges on that production systems are designed to take their welfare, whatever that may be, into account. As long as it is not known, it seems only fair to use the precautionary principle and at least seek knowledge about the welfare potential before initiating production.

According to the third group of views or theories on moral standing of different organisms, that is also firmly placed within the non-anthropocentric views – the so-called biocentric, or life-centred, view – we have direct responsibilities to living entities within the natural environment. That is: all varieties of animals and plants deserve direct moral consideration. Hence, according to this view we have direct duties to insects, independently of their psychological capacities. Another way of putting this is to say that insects have rights, most importantly the right not to be exploited by humans; at least not for non-essential needs or trivial interests. Thus, according to this line of thinking, broader animal ethical issues arise which go well beyond the welfare issues, such as insect integrity, death and naturalness (Gjerris et al. 2016). However, differences of opinion exist about how to express this responsibility. It should be noted that to some this third way of looking at human-nature relations should be entailed in a very strong version of the sustainability concept.

Regardless of how inclusive a view one argues for – in terms of how far-reaching responsibilities one assumes and whether these responsibilities include animals and even insects – it is one thing to determine what entities should have moral standing and quite another to decide how to balance the different concerns such as benefits to (some) humans, respect of moral rights, or risks to other humans, ecosystems or animal welfare. Thus, different ethical concerns may come into conflict in the quest for a more sustainable feed and food production.

3 Are Insects for Food and Feed More Sustainable Than Other Forms of Protein?

Deciding which parameters are relevant when seeking (a higher degree of) sustainability of a product or production method (let alone trying to provide measures for this) not only entails the risk of arbitrariness, but also means choosing among different aspects of sustainability that might not always go hand in hand. Sustainability thus entails value-based choices and the notion of sustainability is essentially shaped according to the interests at stake (Maxey 2007). Moreover, it depends on how alternatives are assessed, and which alternatives that are considered. For example, making an environmental life cycle assessment (LCA), comparing alternatives is far from straightforward for several reasons: Firstly, an (attributional) LCA is bound to be relative to the system in which it is being compared. Moreover, the functional unit needs to be the same in the systems which are compared, which might be difficult to achieve. In addition, a proper factual foundation is paramount, and when it comes to insect production systems, published environmental data is still limited (Halloran et al. 2016). Further, comparing alternative production systems is also difficult, as there is likely to be disagreement or at least different views on which data are relevant. Finally, it should be noted again that the sustainability of insect production obviously will differ depending on the specifics of the individual production systems. All this points towards that discussions are likely persist in terms of how to delineate such assessments, e.g. whether feed used for the insects should be mixed grain or vegetables or organic waste (Abbasi and Abbasi 2016). Another factor which plays a role is that currently (2017) only few real-life studies exist, such as Halloran et al. (2017).

Another issue is whether sustainability can be understood as something absolute (this *is* sustainable) or as something that should be evaluated in comparison with other products/productions methods (this is or more/less sustainable than another system). If the latter is the case, insects for feed and food production should be seen not only relative to the products/production methods that they aim to replace but also with other (realistic) alternatives of providing protein rich food and feed.

Production of insects for food and feed challenges a number of aspects in current farm animal production systems. Moreover, it contributes to a holistic perspective on food production chain, pinpointing that what is considered waste in one system can be used as insect feed in another. Insect rearing might contribute to enhancement of sustainable food systems thanks to lower emissions of climate gases than farm animals (Oonincx et al. 2010) and insects having significantly lower feed conversion rates because of physiological and biological differences (Miech et al. 2016). After adjustment of edible weight crickets need less than half the amount of feed to convert into edible substance (meat) compared to chicken and pig, and six times less than beef cattle (van Huis 2013). However, when crickets are fed the same feed as chickens, some of the same environmental issues arise, including that some ingredients used for feed are directly suitable for human consumption.

Hence, to be a more sustainable alternative, other feed sources are needed. Miech et al. (2016) studied feed conversion rates in crickets reared in Cambodia as related to chicken feed and different weeds. They found no difference between chicken feed, cassava tops and *Cleome rutidosperma*. Further they suggested that by-products from the food industry could also be promising alternatives. Another important aspect is that insects' need of water is far less than that of any mammal (van Huis et al. 2013), and in combination with a high feed conversion efficiency this contributes to limiting both direct and indirect (growing feed) use of resources. In this perspective, insects could promote increased sustainability in protein production for human consumption.

Further, land use for feed production is one of the largest impact factors in climate change, and as insect farms require less space per animal than current animal farming this is an important aspect. A Dutch study showed that mealworm farming has a total lower global warming impact than conventional farming, but relatively high levels of energy use due to thermal comfort temperature for e.g. mealworms and crickets (Makkar et al. 2014). Moreover, efficient transport thanks to dense packing and far less use of energy and less water at slaughter (freezing and deep-frying) also contribute to a lower environmental impact. Another possible indirect sustainability factor is related to the nutritional content of insects. It has been found that amino-acids and omega 3 in mealworms are comparable to that of fish (FAO 2013), opening for possibilities to decrease current overfishing of wild fish populations and water pollution from fish farms by exchanging the source for these nutrients to insects.

Insects reared for human consumption might also improve the situation for wild insects (Halloran et al. 2015). While loss of biodiversity is a global challenge, crops and weeds produced as feed for livestock insects can be a source of feed also for wild pollinators contributing to enhancing or at least sustaining local biodiversity (pers.com. Anna Jansson). This said, it should be noted that a total shift away from animal based protein sources to vegetables and crops might have an even greater potential, as the detour over feed conversion is omitted and vegetables and crops are used directly in human consumption. There are, however, other elements in sustainability such as biodiversity and land use where neither crops nor human activities can replace that of animal grazing.

To sum up, compared to traditional livestock production, insect production often comes out as having a smaller environmental impact. But if it is regarded realistic to move a substantial part of current consumption of livestock protein to insect protein, it could also be seen as realistic to move consumption in other directions to ensure an even more sustainable food production. Here it seems necessary also to compare plant-based alternatives to animal proteins, whether from traditional livestock or insects. Traditional vegetarian protein sources such as chickpeas, lentils, beans etc. is one option. Products like seitan, quorn and tofu are other sources of protein that would need to be compared with proteins from insects. In line with this, several companies are in the beginning of developing (economically) feasible versions of what could be labelled “high-tech” plant based “meat” e.g. the company *Impossible Foods Inc*. Finally, the attempts to develop vat-grown meat from muscle cells (also known as *artificial meat* or *clean meat*) could also be interesting when considering what constitutes a more sustainable food system than the present ones. Such studies are beginning to appear and will provide a better basis for understanding claims about the sustainability of insect production (Smetana et al. 2015; Röös et al. 2016).

The different options do not necessarily exclude each other, but any claims about the sustainability of large scale insect production for feed and food should be compared not only with traditional livestock production, but also with other realistic alternatives. Here it is worth noticing that what is considered “realistic” alternatives might also be up for discussion as the social context matters in terms of acceptability.

4 Ethical Aspects of Changing Eating Habits

Besides choice of definition of sustainability, scrutiny of scientific investigations of insect welfare and the actual climate impact of large scale insect rearing for food and feed, compared to traditional animal sources of protein and other sources of protein, a set of issues related to public acceptance remain to be discussed. That is, even if some ways of producing insects can be shown to be a relatively more environmentally sustainable, climate and animal welfare friendly form of animal protein, this is of little use unless people accept insects as food and feed.

From a historical point of view, entomophagy is nothing new (Gahukar 2011), and is also daily practiced in many parts of the world covering more than 2000 edible insects (Jongema 2015), yet it is classified as a ‘novel food’ (EC 258/97) within the EU. Further, it has been argued in a recent study of consumer acceptance of insect consumption, that it is important to distinguish between initial motivation to eat insects or insect based food on the one hand, and repeated consumption on the other, which, in parallel with other food items, is influenced by other factors such as price, taste, availability and whether it is adoptable to previous eating habits (House 2016). Insects are documented to evoke disgust and fear among some potential target consumers (Verbeke 2015). i.e. among citizens whose consumption pattern in general have a large climate footprint as well as a low interest in livestock welfare. Hence, the scepticism is the largest where the need of changing eating habits is largest, which calls for effective strategies to change behaviours (Hartmann et al. 2015).

As with any shift of social practices towards a more sustainable life style, there is a need for the public's acceptance of a redefinition of what is normal, by including e.g. insect eating into mainstream practices (Kanerva 2016). In order to reform the actual eating and purchasing habits, attitudes and values need to be changed, a process that may run both ways supporting each other (Kanerva 2016). A range of factors influence our eating habits, such as tradition, taste and moral values, and over many years the arguments related to improved personal health has been said to be most influential on changing behaviour. It has been recently argued that aspects related to moral dimensions of food such as cultural, societal and environmental concerns could contribute even more to change eating habits by nuancing the picture of the food chain (Hekler et al. 2010).

Assuming this view is correct, a variety of values that influence food choices can be highlighted such as different definitions of sustainability, comparing climate impact of different protein sources, animal welfare standards in conventional livestock and insect rearing etc. to influence the public's choice in a direction towards insect consumption. If, on the other hand, ethical arguments in favour of animal rights, combined with a biocentric perspective is promoted, insect eating is not an option.

This means that as the aim strived for is related to values, and the values are related to the aim, the entire setting of values and aims need to be changed and promoted to achieve more sustainable eating practices. There is no guarantee that the values included in a shift from traditional livestock production/consumption to insect production/consumption are shared by a significant number of consumers in the Western world, even though the opposite could be true on a global scale as insects is an integrated part of the diet in other areas of the world (cf. FAO 2011). Should this, however, be the case, it is still a difficult task as many decisions are not entirely rational or preceded by a conscious decision-making process. Further, people seem more prone to accept divergences between what they ought to do, and what they actually do, i.e. accepting cognitive dissonance (Ong et al. 2017), than to transform their actions to be in line with their values. Within ethical theory these issues have been dealt with in terms of decision-making.

Within traditional ethical theories such as utilitarianism and deontology, it has been argued that once a criterion or principle for an ethical correct action is founded (e.g. maximising happiness for all moral objects or acting according to a good intention), this should be implemented in terms of applying the theory (or, rather the principle) on the situation. Contrary to such a 'top-down' approach, a 'bottom-up' approach has been suggested to better meet the range of different aspects involved in a decision, such as moral intuition and the actual context. Between these models an interaction model is suggested, that may facilitate creating a balance between ethical principles and context related aspects (Lindström 2012). Within this model public ethical values related to sustainability (e.g. biodiversity, climate mitigation or working conditions) may be related to personal values (e.g. taste, economic situation, habits) and facilitate both coherent decisions and practical decisions that are possible to live by in everyday life to avoid cognitive dissonance.

Further, thanks to the context sensitivity, change of societal values or personal preferences can be included in a continuous decision-making process which may contribute both to redefining normality with regard to eating habits and to take the step to actually adopting eating habits to include insect based food as called for by Kanerva (2016) and House (2016).

5 Conclusion

Is insect production, as an example of mini-livestock (Hardouin 1995), a more sustainable protein source than ordinary (vertebrate) livestock such as chickens, pig or cows or compared to systems providing non-animal based proteins for food and feed? This is difficult question to answer unanimously for several reasons.

First, it depends on how sustainability is defined, and which dimensions and concerns (e.g. human health, environmental impact, socio-economic implications or animal welfare) that are included. Secondly, it depends on how these concerns entailed by sustainability are translated into more concrete criteria and indicators for specific production systems. Thirdly, it depends on how well we are able to measure different aspects; different criteria and indicators, and whether they are equally easy to measure in different production systems to prevent skewedness or bias. Fourthly, it depends on what alternatives (e.g. cows, pigs, lentils – and what production systems) we are comparing with, and how these are described and delineated as there is a wide range of farming systems under which these alternatives are cultivated/reared, and a divergence in insect farming systems from small-scale insect farming and industrial farming systems is very likely. Fifthly, it depends on how these different concerns are balanced against each other.

Finally, one could argue that assessing insect production for food and feed according to a sustainability framework is in itself an ethical decision: who or what counts – do insects have moral standing, and if they do what are their moral significance *vis-à-vis* humans? Evidently, making these kinds of assessment is inherently and immensely complex. This does not necessarily imply that one should refrain from making such assessments, as long as they are done in a transparent way. The point is, however, that the way such assessments are done and what conclusions are drawn are not merely a scientific matter but also involves different value judgements. Thus, disagreement with an assessment can not only be based on scientific arguments but also on differences in underlying ethical values. Consequently, discussions of the future of using insects for food and feed should contain a discussion of the ethical issues.

These ethical issues include a discussion of whether it is found acceptable to use insects merely as means to an end: using insects to provide humans with nutritious food and using insects as feed for other animals. Such a view implies that insects have no moral standing in their own right or, at least, that their moral significance is less than that of humans and the animals they constitute feed for.

Such a stance would be challenged from several non-anthropocentric positions. Some positions claim that it is wrong not ascribing rights to insects such as not to be killed to serve a non-essential human interest. This in turn raises further discussions of what ascribing insects an ethically relevant kind of integrity would be based on and imply. Another way of discussing the ethical acceptability of using insects for food and feed is in terms of comparing welfare interests of humans and other affected sentient beings, thus comparing the welfare gains of humans with possible welfare loss of the insects. The latter include a discussion of two things: (i) a philosophical discussion of whether welfare is the key aspect for determining the acceptability of the use of animals such as insects for food and feed. This discussion can be compared with current discussions of animal welfare within modern livestock production: (ii) a more empirically grounded discussion of whether insects can experience welfare. Do they feel pain, pleasure, suffering and moreover: how to measure this?

Using insects for food and feed and justifying this by pointing to an increased sustainability, is in itself a value based argument relying on a certain view on the ethical importance of insects in the greater perspective compared to for example future generations. Part of the future challenges for using insects for food and feed is thus to enter discussions of the underlying values related to our food and feed systems, and more broadly, to the way we relate to the natural environment.

References

Abbasi T, Abbasi SA (2016) Reducing the global environmental impact of livestock production: the minilivestock option. Journal of Cleaner Production 112:1754–1766

Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision, ESA working paper no. 12-03. Food and Agricultural Organization of The United Nations, Rome

Bosselmann K (2016) The principle of sustainability: transforming law and governance. Routledge, New York

Broom DM (2001) Evolution of pain. Vlaams Diergeneeskundig Tijdschrift 70(1):17–21

Broom DM (2014) Sentience and animal welfare. Centre for Agriculture and Biosciences International, Oxfordshire

Eisemann CH, Jorgensen WK, Merritt DJ, Rice MJ, Cribb BW, Webb PD, Zalucki MP (1984) Do insects feel pain? A biological view. Cell Mol Life Sci 40(2):164–167

Elwood RW (2011) Pain and suffering in invertebrates? Inst Res Anim J 5(22):175–184

FAO (2011) Mapping supply and demand for animal-source foods to 2030, by T.P. Robinson & F. Pozzi. Animal production and health working paper no. 2. Rome. http://www.fao.org/docrep/014/i2425e/i2425e00.pdf

FAO (2015a) Insects for food and feed. http://www.fao.org/forestry/edibleinsects/en/

FAO (2015b) The State of Food Insecurity in the World 2015. Rome: http://www.fao.org/3/a-i4646e.pdf

FAO (2013) The contribution of insects to food security, livelihoods and the environment. Rome: FAO

Gahukar RT (2011) Entomophagy and human food security. International Journal of Tropical Insect Science 31(3):129–144

Gamborg C, Gjerris M (2012) For the benefit of the land? Ethical aspects of the impact of meat production on nature, the environment, and the countryside. In: Potthas T, Meisch S (eds) Climate change and sustainable development. Ethical perspectives on land use and food production. Wageningen Academic Publishers, Wageningen, pp 202–206

Gamborg C, Sandøe P (2005) Sustainability in farm animal breeding: a review. Livest Prod Sci 92:221–231

Gamborg C, Larsen JB (2005) Towards more sustainable forestry? The ethics of close-to-nature forestry. Silva Carelica 49:55–64

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome

Gjerris M, Gamborg C, Röcklinsberg H (2016) Ethical aspects of insect production for food and feed. J Insects Food Feed 2(2):101–110

Goodland R, Anhang J (2009) Livestock and climate change. What if the key actors in climate change are… cows, pigs, and chickens. World Watch Institute, Washington, DC

Halloran A, Roos N, Eilenberg J, Cerutti A, Bruun S (2016) Life cycle analysis of edible insects for food protein: a review. Agron Sustain Dev 36:57. https://doi.org/10.1007/s13593-016-0392-8

Halloran A, Vantomme P, Hanboonsong Y, Ekesi S (2015) Regulating edible insects: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture. Food Secur 7(3):739–746

Halloran A, Hanboonsong Y, Roos N, Bruun S (2017) Life cycle assessment of cricket farming in north-eastern Thailand. J Clean Prod 156:83–94

Hardouin J (1995) Minilivestock: from gathering to controlled production. Biodiversity and Conservation 4:220–232

Hartmann C, Shi J, Giusto A and Siegrist M (2015) The psychology of eating insects: A cross-cultural comparison between Germany and China. Food Quality and Preference 44:148–156

Hekler EB, Gardner CD and Robinson TN (2010) Effects of a College Course About Food and Society on Students' Eating Behaviors. American Journal of Preventive Medicine 38(5): 543–547

Henry M, Gasco L, Piccolo G, Fountulaki E (2015) Review on the use of insects in the diet of farmed fish: past and future. Anim Feed Sci Technol 203:1–22

House J (2016) Consumer acceptance of insect-based foods in the Netherlands: Academic and commercial implications. Appetite 107:47–58

Ilea RC (2009) Intensive livestock farming: global trends, increased environmental concerns, and ethical solutions. J Agric Environ Ethics 22:153–167

Jongema Y (2015) List of edible insects of the world (June 1, 2015). Waageningen UR. http://www.wageningenur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm. Accessed 17.01.17

Kanerva, M (2016) Meat eating as a practice and the acceptance of radical change. In Olsson, I.A.S., Araújo, S.M. and Vieira, M.F. (eds.) Food futures: Ethics, science and culture. Proceedings of the EurSafe 2016 conference in Porto, Portugal 29 September – 1 October. Wageningen Academic Publishers

Lindström N (2012) Förhållandet mellan praxis och teori inom etiken, Lund Studies in Ethics and Theology 16

Makkar HPS, Tran G, Heuzé V, Ankers P (2014) State-of-the-art on use of insects as animal feed. Anim Feed Sci Technol 197:1–33

Maxey L (2007) From "alternative" to "sustainable food", in Maye D, Holloway L and Kneafsey M (eds.): Alternative food geographies. London: Elsevier, pp. 55–75

Miech P, Berggren Å, Lindberg JE, Chhay T, Khieu B, Jansson A (2016) Growth and survival of reared Cambodian field crickets (*Teleogryllus testaceus*) fed weeds, agricultural and food industry by-products. J Insects Food Feed 2(4):285–292

Nel WP, Ward JD (2015) Towards a rational sustainability framework. Sustain Sci 10(3):515–520

Norris K, Potts SG, Mortimer SR (2010) Ecosystem services and food production. Issues Environ Sci Technol 30:52–69

Ong ASJ, Frewer LJ and Chan M (2017) Cognitive dissonance in food and nutrition – A conceptual framework. Trends in Food Science & Technology 59:60–69

Oonincx DGAB, van Itterbeeck J, Heetkamp MJW, van den Brand H, van Loon JJ, van Huis A (2010) An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. PLoS One 5(12):e14445. https://doi.org/10.1371/journal.pone.0014445

Röös E, Patel M, Spångberg J, Carlsson G, Rydhmer L (2016) Limiting livestock production to pasture and by-products in a search for sustainable diets. Food Policy 58:1–13

Sala S, Assumpcio' A, McLaren SJ, Notarnicola B, Saouter E, Sonesson U (2017) In quest of reducing the environmental impacts of food production and consumption. J Clean Prod 140:387–398

Sherwin C (2001) Can invertebrates suffer? Or how robust is argument-by-analogy. Animal Welfare 10:103–18

Smetana S, Mathys A, Knoch A, Heinz V (2015) Meat alternatives: life cycle assessment of most known meat substitutes. Int J Life Cycle Assess 20(9):1254–1267

Smith JA (1991) A question of pain in invertebrates. Inst Lab Anim Res J 33:25–31

Sneddon LU, Elwood RW, Adamo SA, Leach MC (2014) Defining and assessing animal pain. Anim Behav 97:201–212

Söderbaum P (2014) The Role of Economics and Democracy in Institutional Change for Sustainability. Sustainability 6(5):2755–2765

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow – environmental issues and options. Food and Agricultural Organisation of the United Nations, Rome

Steinfeld H, Mooney HA, Schneider F, Neville LE (eds) (2013) Livestock in a changing landscape. Volume 1: Drivers, consequences, and responses. Island Press, Washington, DC

The Lancet (2013) Executive summary of the lancet maternal and child nutrition series. The Lancet. http://www.thelancet.com/pb/assets/raw/Lancet/stories/series/nutrition-eng.pdf

United Nations (2015) The sustainable development agenda. The United Nations. http://www.un.org/sustainabledevelopment/development-agenda/

United Nations, Department of Economic and Social Affairs, Population Division (2015) World population prospects: the 2015 revision, key findings and advance tables, Working paper no. ESA/P/WP.241. United Nations, New York

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects: future prospects for food and feed security, FAO forestry paper 171. Food and Agricultural Organisation of the United Nations, Rome

Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Quality and Preference 39:147–155

Wheeler T, von Braun J (2013) Climate change impacts on global food security. Science 341(6145):508–513

Marketing Insects: Superfood or Solution-Food?

Carolin Schiemer, Afton Halloran, Kristjan Jespersen, and Petra Kaukua

Abstract In entering Western markets, edible insects are typically framed as the 'solution' to a number of challenges caused by unsustainable global food systems, such as climate change and global health issues. In addition, some media outlets also frame insects as the next 'superfood'. Superfood is a marketing term for nutrient-packed foods, which are successfully promoted to Western consumers with the promises of health, well-being and beauty. However, the increase in the demand in the West is argued to cause negative social, environmental, economic and cultural consequences – externalities – felt by those who traditionally produce and consume the foods. These actors are located far away from where the superfood phenomenon materializes. Therefore, we detect a possibly contentious framing strategy through double-framing insects as both a solution and a superfood. We ask: how can insects be promoted as the solution to the negative externalities that arise from unsustainable Western consumption patterns, while at the same time being framed as a 'superfood', which cause those very externalities? As a point of departure for this chapter, we build on the research article *Entomophagy and Power* by Müller et al. (J Insect Food Feed 2(2):121–136, 2016), who raise a concern that the growth of Western insect industries might reproduce, rather than challenge, power imbalances in global food systems. Our analysis suggests that the tensions of double-framing insects as both 'solution' and 'superfood' might be the first step of pushing insects towards an unsustainable future, particularly because of two pitfalls common for superfoods: firstly, the homogenization of diverse practice, and secondly, universalized sustainability and apolotical solutions. However, our study finds also that insects differ from superfoods for two main reasons: for insects' ability to add value locally and because of the involvement of sustainably-driven actors from the

C. Schiemer (✉) · K. Jespersen · P. Kaukua
Department of Management, Society and Communication, Copenhagen Business School, Frederiksberg C, Denmark
e-mail: carolin.schiemer@gmail.com; petrakaukua@gmail.com

A. Halloran
Department of Nutrition, Exercise and Sports, University of Copenhagen, Frederiksberg C, Denmark

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_14

beginning of industry formation. Due to these differences, this study concludes that if the superfood pitfalls are avoided, insects have a potential to become a truly ‘sustainable superfood’.

1 Introduction

In entering Western markets, edible insects are promoted for their high protein and other nutritional content, low greenhouse gas emissions of their production, and the high efficiency at which they can convert feed into food (van Huis et al. 2013; Rumpold and Schlüter 2013; Halloran et al. 2015). If embraced by Western markets, some scholars argue that insects could be suitable for replacing unsustainable food consumption and production patterns, thereby mitigating the devastating effects of livestock farming on the climate (Steinfeld 2006; Stehfest et al. 2009; Oonincx and de Boer 2012; Vantomme et al. 2014; Payne et al. 2015). Furthermore, insects' democratic potential to empower the poor and other marginalized groups, such as women, is often highlighted because insects are small and easy to breed, without much investment capital, skills, education or space for rearing needed (Durst et al. 2010; van Huis et al. 2013; Vantomme et al. 2014; Kelemu et al. 2015).

Despite being traditionally consumed in many countries of the world for millennia (Ramos-Elorduy 2009; van Huis et al. 2013), only over the past few years the sudden attention to this topic has resulted in rapidly growing interest of a variety of actors, who are ready to tap into the diverse potential insects are promising (Dossey et al. 2016). In 2014, FAO and Wageningen University and Research (hereafter referred to as WUR) organised the international conference “Insects to feed the world”, and this gathering of international industry leaders, insect breeders, universities, non-governmental organisations (hereafter referred to as NGOs) and other stakeholders had a clear message: “Insects for feed and food are viable solutions for the protein deficit problem” (WUR 2014). In that sense, edible insects are claimed to have potential for food and feed security. Due to their high protein content they could supplement the conventional production of meat for direct human consumption or for indirect use as feedstock in the face of an increasing world population and quest for alternative protein sources (FAO & CIRAD 2015). However, a look at the list of conference participants reveals that despite insects are promoted as a global solution, less than 20% of the conference participants travelled from what we consider as parts outside the global West (Vantomme et al. 2014), from areas where ‘solutions’ against food crisis are needed the most (van Huis et al. 2013). With West, we refer to the geographical entity encompassing Europe, North America, North Asia, Australia and New Zealand, which also happen to be countries with high GDP (UNDP 2015) where entomophagy is commonly not practiced (DeFoliart 1999). The bias is also reflected in entrepreneurship: in research conducted by Dossey et al. in 2016, of 98 companies known to offer insects as human food or animal feed, 73 were founded during 2013 and 2015 of which the majority is based in the global West (Müller et al. 2016), rather than in areas where insects are traditionally produced and consumed.

In addition, due to insects' nutritional qualities a number of Western media sources (e.g. Haiken 2014; Pantsios 2015; Blake 2017) have started to also frame insects as a 'superfood' – a designation which promotes foods for being "especially beneficial for health and well-being" (The Oxford Dictionary 2016). Superfoods are particularly popular amongst Western consumers (Mintel 2016). But instead of solving the global issues such as food and feed insecurity (Barrie 2014; van Allen 2014), the superfood phenomenon has recently been criticized by media for causing a number of negative effects felt in traditional producer and consumer communities. These negative effects, hereafter referred to as externalities, include environmental depletion and exploitation of labor, which are claimed to be caused by starkly increasing Western demand in superfoods (Blythman 2013, 2016; Kimball 2015). Negative externalities can therefore be understood as a loss in the welfare of one party resulting from an activity of another party, without there being any compensation for the losing party (Callon 1998). In the case of superfoods, it is argued that the poor and marginalised actors located outside the West, the losing party, have to cover the costs for solving and repairing the damage caused by the winning party, the West, largely themselves.

The concept of externalities reveals a possibly contentious framing strategy through double-framing edible insects as both a solution and superfood. According to Entman (1993), "to frame is to select some aspects of perceived reality and make them more salient in a communicating text". The purpose of frames is "to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described" (p. 52). Applying this understanding of frames to edible insects leads to the following issue: how can edible insects be promoted as the solution to the negative externalities that arise from unsustainable global food production and consumption patterns, while at the same time being framed as externality-inducing superfood?

This chapter focuses on the concerns arising from inconsistencies of the solution-frame in terms of promoting global food security, consumer acceptance and economic, social and environmental sustainability. Therefore, the main objective is to shed light on where claims and practices concerning insects framed as a superfood and a solution align, and where they do not. Our study builds on the findings and methodologies of the research article *Entomophagy and Power* by Müller et al. (2016), who raised a concern that the demand in and growth of insect industries located in the West might in fact reproduce, rather than challenge, the aforementioned power imbalances in global food systems. Using their findings as a lens for studying superfoods, the following research question will be tackled: To what extent does the superfood frame impact insects' global sustainability performance? First, in order to find out how negative externalities arise in superfood markets, a case-based comparative superfood media study of three food items framed as superfoods is conducted. Secondly, findings from the superfood media study are evaluated against current development of the rising Western insect industry. Next, frames of superfood and solution-food communication in the West are analyzed. In a marketing claim study, marketing texts of solution-framed food products are contrasted to those framed as superfood. Finally, the tensions that might arise if insects are framed both as superfood and solution-food are discussed, and lastly we will provide recommendations on how to avoid superfood-specific pitfalls that could lead to unsustainable development.

2 Methodology

2.1 Superfood Media Studies

The purpose of the superfood media study was to understand what factors and which actors define how a food item becomes labelled as a superfood and what effects the superfood title has on markets and its actors. To study this, secondary qualitative research on three superfood-labelled food items, açaí, avocado and quinoa, was conducted. These particular foods were chosen based on four criteria: (1) sufficiency and relevancy of information available and their online accessability; (2) the possibility of replication logic of similar shared qualities and events taking place during the 'lifecycle' of each food item in question, which allows to produce what this paper calls the 'life of a superfood' model; (3) the chronological succession of peak interest of the superfood, as shown in Google Trends[1]; and (4) comparability of frames: açaí and avocado are dominantly framed as superfoods, while quinoa is in addition to being framed as a superfood also framed by FAO as a solution to contribute to global food security (FAO & CIRAD 2015).

Possibly due to the absence of legal recognition surrounding the term 'superfood' (CBI 2015), a thorough search of academic databases has shown that only a limited number of scientific articles was available. However, as the media representation of the superfood phenomenon is strongly influencing the perception of the foods, in this study Google and Faktiva were searched to find online newspaper articles and blog posts which allowed to study how the media perception of the food item has evolved over time[2].

[1] See trend development for acai, quinoa, avocado and edible insects from 2004–2016 here: https://trends.google.com/trends/explore?date=all&q=Acai,Avocado,Quinoa,edible%20insect*.

[2] The guiding research questions for studying superfoods are the following: What is the traditional state of the food item in question? How does the food item enter the West? Who begins to frame the food item in question as a superfood? What qualities is the food item promoted for? Which externalities does a food item's superfood status cause for its traditional consumers and producer communities? Who are the key actors in the process of 'superfoodization', whose voice is being heard, who is being excluded from the conversation, and who is driving the change? What rules, norms, incentives and values guide behaviour? What tensions arise along the process of 'superfoodization'?

2.2 Literature Review of Edible Insects in the West

In order to study edible insects' 'superfoodization' in Western markets, qualitative secondary research in the form of a systematic literature review was conducted. Employing the methodology of Müller et al. (2016), Web of Science, PubMed, Scopus and Wageningen Academic Publishers databases were searched on March 8, 2017 and March 10, 2017, using the search terms 'edible insect', 'entomophagy', 'eating insects', 'insect consumption' and 'insects as food'. We encountered a total of 539 peer-reviewed journal articles, which were reduced to a total of 105 articles[3].

2.3 Marketing Claim Study

In this study we tested the extent to which marketing claims of predominantly superfood-framed foods and predominantly solution-framed foods match, resemble and differ when these products are marketed in the West. To do so, we textually analyzed marketing text of products that were made of or contained açaí, avocado and quinoa and are pre-dominantly framed as superfoods. Then, we compared the superfood marketing claims to the findings of Müller et al. (2016), who studied the marketing text of products made of or containing edible insects, which are predominantly framed as a solution-food. Müller et al. (2016) identified eight themes which were promoted in insect marketing in the West: Health/wellness; Taste; Environment; Food safety/quality; Food security; Promise/motivational; Power; and Acceptance[4]. They then identified the popularity of each theme by counting and grouping emerging marketing terms used for marketing edible insects in the West into the themes in question.

In order to ensure comparability of our textual analysis of claims used for marketing pre-dominantly superfood-framed foods in the West to the data of Müller et al. (2016), the authors' methodological approach was applied to our study of superfood marketing claims. To do so, a systematic review of products available in the West that include açaí, avocado and quinoa was conducted, using the Google US search engine on April 20–21, 2017. Search terms "Acai for sale"/"Avocado for sale"/"Quinoa for sale" displayed approx. 15,000,000 results for açaí, 16,700,000 results for avocado, and 18,300,000 results for quinoa.

For each superfood, we compiled a list of companies that offer the superfood item in question for human consumption. These companies were selected as they (1) appear in sequence on Google; (2) sell products that were: made of or containing any of one of the three selected superfoods; currently available to order online by

[3] To ensure comparability to the superfood media studies, the research questions for studying edible insects are the same as for superfoods.

[4] For more insight into the terms and themes identified by Müller et al. (2016) used for analyzing marketing claims for edible insects, see www.wageningenacademic.com/doi/suppl/10.3920/JIFF2016.0010/suppl_file/jiff2016.0010_esm_s5_categories+and+codes+used+in+analysis.pdf.

end consumers; and branded by the company itself. We limited the amount of products per superfood to 20, so the total number of companies included was 39, and the total number of superfood products was 60. For each company, its name and the country in which the company sells its product was recorded. Then, data on up to five products per company was collected, using either (1) the top five 'best sellers' (according to the website) or (2) if these were not explicitly stated, the first five products in the total product list. Excluded were products that were: not (yet/any more) available for purchase; explicitly for wholesale only; not advertised in English; not available via online order; not including any product description.

For textual analysis, we copied the marketing text from the company websites used to market the selected superfood products. Next, we measured how frequently the specific themes and associated terms identified by Müller et al. (2016) were appearing also for the superfoods. As insects belong to the animal category, some adaptations to the existing dataset of Müller et al. (2016) were made. Based on subjective selection criteria, we subjectively excluded terms which in our view relate to livestock/animal breeding or insects directly: 'feed conversion ratio'; 'greenhouse gas emissions' 'CO2'; 'taboo'; 'icky'; 'yuk' 'yuk factor'; 'scare' 'scary' and 'insects are the…'. For full details of methodologies for all studies, see Kaukua and Schiemer (2017).

3 What Makes a Food 'Super'?

3.1 Promises of Health and Well-Being

> *"Scientists Think Cockroach Milk Could Be the Superfood of the Future. Move over kale." – Headline of a Science Alert article by Jacinta Bowler, 2016.*

Above, Bowler (2016) refers to a study in the *Journal of the International Union of Crystallography*, which investigated the structure of milk protein crystals found inside baby Pacific beetle cockroaches. The study claims that this "milk" may serve as a potential protein supplement for humans, containing three times the energy of dairy milk and all essential amino acids (Banerjee et al. 2016). The media article states that insects are "the key" for feeding the world by providing a sustainable source of protein and nutrients for growing populations in developing countries, as well as in the West. These qualities, Bowler states in the article, make insects a superfood. While no scientific articles were found using the superfood term to describe edible insects, a Google search shows for the search term 'insect superfood' approximately 725,000 results and an increasing number of magazines, blogs and newspaper articles are naming "insect superfood" the "hottest health food trend" (Blake 2017), "the next new miracle superfood" (Haiken 2014) and "the superfood of the future" (Blakely 2014).

In an attempt to explore the meaning of the superfood title, it becomes apparent that no legal or scientific definition exists (CBI 2015). Rather, superfood is a marketing term promoting certain foods that are associated with high concentrations of vitamins, minerals, fibers, essential fatty acids, or antioxidants (Fleming 2014; CBI 2015; SuperfoodBlog 2017). They are often promoted for being particularly rich in protein, a nutrient which "[Westerners] are having a wild love affair with". In quest for "leanness, energy, and high performance" (Barrie 2014), Western consumers constantly seek the next, protein-packed powerhouse – even though most eat more protein than the recommended daily amount (Jones 2012).

The label also comes with significant sales potential: from 2014 to 2015, there was a 202% increase globally in the number of superfood products (Criddle 2016), and a 2014 UK poll found that 61% of respondents had purchased a food item purely because it had been labelled as such (YouGov, in Shearman 2014). The top countries with launches of food and drink products including the term "superfood" are USA (30% of the superfood product launches), Australia (10%), Germany (7%), United Kingdom (6%) and Canada (6%) (Mintel Group Ltd 2016), demonstrating that superfoods are mostly a phenomenon created and enjoyed by the West.

These figures suggest that a superfood frame could work as an appealing promotional strategy for previously unknown food items. For that very reason, we argue that the superfood frame could potentially increase insects popularity in the near future, particularly to overcome the considerable reluctance that is still felt among Western consumers, who often compare edible insects to starvation food (DeFoliart 1999; House 2016). Promoting insects as the 'next superfood' also seems to fit perfectly to current food trends. Mintel Group Ltd (2016), a global consumer research company, reveals that consumers are increasingly reflecting their values through purchasing behaviour: in the *Food & Drink Trends 2017* report, Mintel Group Ltd (2016) predicts that consumer trends are moving towards 'Sustainable Consumption' and 'Health for Everyone'. As a part of 'Sustainable Consumption', Western consumers desire less processed foods, and the idea of reducing the consumption of traditional protein sources like red meat is gaining popularity. Furthermore, 'Health for Everyone' suggests that consumers are looking for protein-packed diets and healthy foods that also promote affordability and accessibility for all. Inequality is therefore not just a political or philanthropic issue – it is a subject that will increasingly resonate with the food and drink industry (Mintel Group Ltd 2016). But how exactly becomes a food item credited as 'super' and what effects does the status have on actors and the environment?

3.2 The 'Life of a Superfood' Model

This section summarizes the results of our qualitative superfood study of açaí, avocado and quinoa. Similar and recurring events found in all three foods were grouped into five distinct phases: (Phase 0) Traditional state, (Phase 1) Entering the West, (Phase 2) Superfood hype, (Phase 3) Contested frame, and (Phase 4) Stabilisation (Table 1). Below, these superfood-distinct phases are presented in the *life of a superfood* model.

Table 1 'Life of a Superfood' Model

Phase	0: Traditional State	1: Entering the West	2: Superfood hype	3: Contested frame	4: Stabilization
Market	Local markets	Global niche markets: health-consciousness	Global mass markets: superfoods	Market collapse/ stagnation	Market for sustainable goods
3.3. Actors	Indigenous communities Rural communities	Commissions Consumers Entrepreneurs Farmer co-ops Governments R&D Scientists	Businesses Consumers Celebrities Marketers Media	Academia Businesses Consumers Media Nutritionists and health experts Research	Governments IGOs Media NGOs Research Standard setters
3.4. Qualification and Marketing	Staple Delicacy Medicine	Medicine Health Exotic First mention of superfood	Exaggerated promises of health, well-being and beauty Superfood Application in everyday products Media and TV Mass events Celebrity endorsement Nutritional primitivism	Scams Call for boycott Unsustainable Crime Exploitation	Promises of health for all and sustainable consumption Solution Sustainable superfood Standardised

3.2.1 Phase 0: Traditional State

The foods generally come from non-Western countries and are commonly situated in the tropics or subtropics. For example, açaí is native to the Brazilian amazon rainforest (Aquiar et al. 2012), quinoa comes from the Bolivian altiplano mountain region (Hamilton 2014) and avocados originate from the Mexican subtropics (Saner and Morales 2015). The food item has often been a staple food in indigenous diets for thousands of years. It is consumed as a delicacy and in many cases applied as alternative medicine by local communities, forming an important part of tradition and heritage. The food usually plays an important role as a source of income in many low-income or rural producer communities (Abrams 2016).

3.2.2 Phase 1: Entering the West

The food item then becomes 'discovered' by Westerners. Different actors are at play: local farmer co-ops might combine forces to bring the food to global markets (Kerssen 2015), but in some cases Western start-ups, recognize the business opportunity and begin to pursue marketing efforts in order to bring the previously unknown product to Western supermarkets (Watson 2013). Research about this new food item is mainly financed by Western companies, exploring how to exploit the business potential. Subsequently, the first marketing strategies are created, backed up by assumed medicinal and health promises to the niche market of health-conscious consumers (Abrams 2016).

3.2.3 Phase 2: Superfood Hype

As the media discovers the food item's potential to improve health and well-being, it starts to appear on various media outlets as the 'next superfood', e.g. on websites, health blogs and newspaper articles. Attached to it are particular claims of health, well-being and beauty promises, such as its ability to slow aging, reduce cholesterol or support weight loss (CBI 2015; Kimball 2015; Loyer 2016). Part of the allure of many superfoods also comes from their exotic origin, and they are promoted with names like the "Andean miracle grain" (Wepman and Wepman 2009) or "favourite food of the Aztec Indians" (Jockers 2012). These titles suggest that the food item must have extraordinary qualities as it fuels people living in these – from a Western perspective – 'challenging' subsistence conditions. Therefore, superfoods are perceived as something between a food and a medicine (Loyer 2016). Adding to the media presence of superfoods, Hollywood actors and other celebrities, beauty icons and TV doctors promote these foods as a key to their admired looks and lifestyle (Khazan 2015; Orenstein 2016). As a result of these intense promotional efforts, the superfood title is normalized into the food item, and the sales are skyrocketing.

3.2.4 Phase 3: Contested Frame

Over the course of time the 'superiority' of these foods becomes increasingly questioned. For example, while a number of studies have proven the antioxidant content of some superfoods, others state that many of the fruits, berries and grains considered staples in Western diets are just as efficient sources of vitamins, nutrients and protein (Hancock et al. 2007). Concerns are raised particularly about scam products: for example, in 2008 açaí weight loss pills were exposed as a hoax, as it turned out that there was no scientific evidence of weight loss resulting from the use of the açaí pills (Watson 2013). Critics told consumers not to "waste" their money on these products (Weisbaum 2010), and the negative press had significant consequences on açaí sales worldwide: after the growth of 32% from 2008 to 2009 in the US, from 2010 to 2011 the market experienced a 6.2% drop in sales (Reuteman 2011).

The superfood phenomenon is also marked by sustainability controversies, often caused by the sudden and uncontrolled spike in demand. In the case of quinoa, the superfood boom caused price hikes also in the farmer communities, and it was argued that "poor Bolivians" could no longer afford their staple (Blythman 2013). Similar consequences were reported in açaí markets (Brasileiro 2009). While the international market growth and higher prices should mean higher incomes for farmers, in reality the superfood phenomenon is accused to mainly direct the profits into the pockets of Western corporations who control the supply chain (Brondízio 2008; Pegler 2015). As a consequence, rather than improving the socio-economic status of farmer communities, market growth often further intensifies global power imbalances (Pegler 2015). The superfood 'hype' creates also other far-reaching effects; for example, in the state of Michoacan in Mexico, criminals have recognised the high value of avocado. As a consequence, a number of plantations are now controlled by drug cartels, causing violence, thefts and murders in avocado producing communities (Stone 2015; Muston 2015).

Furthermore, negative environment impacts and the rise of serious health issues in producer communities becomes a concern as superfood production intensifies. For example, the rapidly growing demand for avocado is driving deforestation in order to make way for the profitable fruit plantations, and in Mexico, illegal cultivation has spread to conservation areas (Gonzalez Covarrubias 2016; Mills 2016). Water usage also has become a serious problem particularly in Chile, as in some cases, over 300 liters of water is required to grow just one avocado in areas which already suffer from drought (Stone 2015). Similar concerns have been raised in the Andes, where quinoa monoculture has driven erosion and imposed strain on the country's scarce water resources (Jacobsen 2011). In addition, locals living near avocado plantations have reported lung, kidney and liver problems, caused by river waters contaminated with pesticides released from superfood farming (Gonzalez Covarrubias 2016).

As a consequence, Western media calls for a boycott of the superfood as a way to stop these negative externalities from developing further (Smith 2012; Blythman 2013). However, also the boycotts carry the risk of unintended repercussion: as a response to the quinoa quarrel, Kasterine (2016) claims that if consumers stopped buying quinoa, farmers would lose the incomes they were earning for their native grain. Furthermore, the revelation of the açaí scam led to a significant drop in demand and fluctuations in prices, and these effects are felt usually strongest by farmers and their immediate communities, whose incomes are dependent on the prices they are able to charge (Pegler 2015).

3.2.5 Phase 4: Stabilization

Eventually, the news about exaggerated promises and sustainability quarrels cause the superfood to 'step down' from the spotlight. It might even become featured in articles like "Superfood Stars - Where Are They Now?" (Kingsley 2015), as the attention is directed to the next food promising health, beauty and a longer life. But negative press does not mean that consumers stop buying the superfood altogether. Even though the rate of market growth slows down as the hype stabilizes, the overall demand of the food item keeps growing slowly and steadily (Kugel 2010; Muston 2015; Vos 2016).

In order to cope with negative social and environmental externalities that have risen from the boom, efforts by NGOs and inter-governmental organizations (hereafter referred to as IGOs) such as the Food and Agriculture Organisation of the United Nations (hereafter referred to as FAO) are put in place. For example, 2013 was declared by FAO as the 'International Year of Quinoa', which aimed to bring world attention on the “forgotten” crop’s socio-economic potential. FAO acknowledged that quinoa is not just healthy for those who consume it, but also suitable for feeding the world’s growing population while offering a livelihood opportunity for impoverished producer communities (FAO & CIRAD 2015; Hamilton 2014). If internationally recognized standards are absent, actors start to develop their own, resulting in a multiplicity of standards and fragmentation of traditional superfood industries, as seen in quinoa (Lyon 2015). Often, these standard setters are private businesses which operate in the respective superfood field. For example in 2009, Sambazon, American açaí beverage and food company, created the first EcoCert fair trade certificate for açaí, which ensures economic stability for its farmers (BCtA 2015). Later in 2011, Sambazon joined Business Call to Action, an initiative under UN Global Compact with reported improvements in forest management, job creation, improving life standards and education opportunities for the local population (BCtA 2015). Such actions drive sustainable development in the particular market forward as standard setters and organizations undertake R&D to create solutions for sustainable production, processing and harvesting methods, often in collaboration with the local communities. In this context, the food item may also be recognized for its socio-economic (Pegler 2015) and environmental sustainability potential (FAO & CIRAD 2015). As a consequence, some superfoods become promoted as a ‘solution’, considered as a tool for advancing sustainable development.

3.2.6 Short Summary of the ‘Life of a Superfood’ Model

To summarize, the model highlights the powerful possibilities of marketing unfamiliar food items to new consumer groups. However, the model also brings forth the far-reaching harmful effects Western consumption patterns and powerful marketing tactics might have on marginalized and less powerful groups of actors in the supply chain and the environment. This becomes a particular concern in the case of edible insects, which are promoted for their assumed ability to resolve a multiplicity of sustainability issues. The ‘life of a superfood’ model suggests that if insects are framed as a superfood, they might in fact cause those harmful effects, which are normally observed in superfoods when the market begins to grow (during the superfood Phase 2). Therefore, the extent to which insects are likely to cause the same negative externalities as superfoods, and whether they develop through similar phases as described in the superfood model, will be explored next.

4 Insects: A Sustainable Superfood?

Based on a comparison of the lifecycles as concluded in the ‘Life of a Superfood’ model and compared to the literature available about insect consumption in the West, it is identified that insects are currently in Phase 1 of ‘superfoodization’[5].

[5] For a full analysis, see Kaukua and Schiemer (2017).

Insects are currently entering the West, which is facilitated by the new Novel Food Regulation in the EU and encouraged by the rise in insect entrepreneurship and large-scale R&D projects (Manuell 2016). However, compared to superfoods, insects differ in two major aspects. First, insects have a potential to add value locally, and second, sustainability-driven organizations are involved in the discourse from the beginning of the industry formation (Kaukua and Schiemer 2017). Because of these differences, we claim that insects are *not yet* likely to cause the same kind of externalities as other superfoods.

4.1 Adding Value Locally

Findings from the superfood media study has brought forth that in the case of açaí, avocado and quinoa, externalities tend to emerge mostly in traditional producer and consumer communities as interaction with the West increases. The stark demand by Western consumers and subsequent intensified production often results in externalities such as environmental depletion (Mills 2016) or unfair working conditions (Brondízio 2008). Tackling the externalities remains a challenge for these communities, who are located in less developed regions of the world and often lack power in global supply chains. Bourdieu (1984) argues that power imbalances between the West and these traditional producer communities are informed by actors with more opportunities to carry out their will, and due to unequal access to material and symbolic resources, social inequality is reproduced. With that understanding, traditional producer and consumer communities will remain powerless as long as they are outside the productive spheres of Western superfood markets, as superfood profits continue to predominantly benefit Western businesses which are owned by people from the West (Brondízio 2008; Pegler 2015).

For Western insect products which are framed as superfoods, however, we dispute that the negative externalities as described throughout our superfood media study are not (yet) likely to occur. That is because of two main reasons. First, insects have the ability to add value locally. While there exists some examples of insect exports to Europe, current regulations drastically restrict international trade and interaction with communities who tradtionally produce and consume insects due to issues such as food safety (Halloran et al., 2015). But most importantly, while farming of exotic superfoods is typically restricted to climate-specific conditions, insect rearing can be effectively carried out independent of the location (Van Huis et al. 2013; Müller et al. 2016). In fact, insect rearing is already occurring in the Western hemisphere (Müller et al. 2016; Dossey et al. 2016), and there is significant interest in funding and further developing the Western insect industry (Yates-Doerr 2015), as witnessed in countries such as the Netherlands, United Kingdom and Belgium (Van Huis 2016). In Denmark, the industrialization of the sector is encouraged by the government, which seeks to localize food production as a means to break institutional lock-in of unsustainable, resource-consuming conventional livestock farming, such as swine production

(Boskov-Hansen 2017). Another goal of the industry development is to enhance local employment (Boskov-Hansen 2017; DTI 2017), highlighting the democratic potential of insects as a more socially sustainable food. The ability to add value locality allows for insects to be reared in all sorts of contexts, exercised by all sorts of people (Müller et al. 2016), effectively and intentionally limiting the ambition to import from traditional insect eating communities, such as Kenya or Thailand. These factors, we argue, are likely to moderate the degree of future interaction between the West and traditional insect eating communities.

4.2 Involvement of Sustainably-Driven Actors in the Beginning of Industry Formation

When comparing insects' lifecycle to that of superfoods, it is observed that while insects are positioned in superfood Phase 1, a different set of actors is involved during industry formation. The 'Life of a Superfood' model shows that market creation is usually driven by entrepreneurs, farmer co-ops and R&D motivated to exploit the business opportunity within the market of health-conscious consumers. While this is observed also for insects, sustainability-driven IGOs like FAO, research hubs such as WUR or standard-setters such as inVALUABLE – to date EU's largest insect research project located in Denmark (DTI 2017) – are facilitating the discourse from the beginning. We argue that these actors, which usually only appear in superfood Phase 4, could bring stability into critical processes during industry formation, so that environmental sustainability, socio-economic issues and structural inequalities could be tackled and solutions integrated into decision-making processes from the very beginning. The force of collective and dispersed action by a set of different actors with different worldviews, knowledge and experience who collaborate, compete and contest could eventually lead to building productive institutional logics that will guide the most suitable sustainability identity for the industry (Randels & Laasch 2016). It should not go unmentioned, however, that despite the benefits of having sustainability-driven actors on board early on, there is a risk that insects might be used as a flagship to talk about sustainability, while leaving the 'how' of achieving long-term structural change for later (Yates-Doerr 2015; Müller et al. 2016).

To sum up, the possibility of adding value locally and the presence of sustainability-driven actors early on could prevent that the newly-forming insect industry follows the same unsustainable path as other superfoods have exemplified in the past. However, a major concern is that more research needs to be produced to understand the full environmental, social, environmental and cultural costs and benefits of insect rearing in comparison to conventional food production (Halloran et al. 2015). For example, more insights may reveal hidden environmental costs, which, as Müller et al. (2016) find, tend to go unmentioned in marketing insect products – an issue which will be explored next.

5 Marketing Claim Study: Exploring Marketing Tactics in Superfood- and Solution-Frames

The purpose of this marketing claim study was to test the extent to which marketing claims of predominantly superfood-framed foods and predominantly solution-framed foods match and differ. In this section, we discuss the study's results by exploring frames in superfood and solution-food communication. The purpose of the investigation was to comprehend which specific problem definition (Entman 1993) and aspects of reality each frame deliberately promotes, and which parts remain excluded. To do so, we analyzed marketing text of açaí and avocado products, which are predominantly framed as a superfood. These results were compared to quinoa, which is framed both as a superfood and a solution-food, and finally edible insects, which are predominantly framed as 'the solution'. By focusing on the "words, images, phrases, and presentation styles" (Druckman 2001, p. 227) that are used to construct the stories around superfoods and solution-foods, we developed an understanding of how in superfood- and solution-food marketing information is organized and packaged effectively for potential consumers (Gitlin 1980).

The conceived words or terms occuring in superfood marketing text were grouped into the following themes identified by Müller et al. (2016): Health/wellness; Taste; Environment; Food safety/quality; Food security; Promise/motivational; Power; and Acceptance. To move up the level of abstraction, within the theme Health/wellness the following terms most frequently appeared in marketing text, featuring specific health-enhancing characteristics: 'antioxidant' (açaí), 'healthy fat(s)' (avocado), 'gluten-free' (quinoa) or 'protein' (insects). References to Taste were made by describing superfoods and insects as e.g. 'delicious', whereas the theme Environment emphasized 'local', 'sustainable' or 'organic' modes of production. Assured Food safety/quality was communicated through using terms such as 'safe', 'pure' or 'standard', while Food security highlighted superfoods' and insects' ability to be a 'staple' 'for everyone' and a 'global movement' in the 'world'. The category Promise/motivational encouraged consumers to buy superfood and insect products by employing terms such as 'perfect', 'fresh' or 'easy' in their marketing texts. Characteristics for the theme Power, thematizing dynamic and potentially mutable power relations between various actors that inform the superfood and insect phenomena (Müller et al. 2016), utilised 'empower' 'small farmer(s)', 'poverty', 'equality'', 'democratic' or 'humanitarian'. Finally, to achieve Acceptance of foods, terms such as 'tradition', 'ancient' or 'exotic' and novel' were employed.

The results for themes in marketing claims for both superfoods (here: açaí, avocado and quinoa) and solution-foods (here: quinoa and edible insects) are displayed in Table 2, ranking from most commonly appearing theme (Rank 1) to least popular (Rank 8). The goal is to facilitate the reader's understanding of how specific themes progress as frames change from superfood towards solution-food and back, and where they stay the same.

The results of the textual analysis clearly highlight that topics found in marketing superfoods and solution-foods mostly match and resemble. There was a high

Table 2 Themes in marketing of superfoods and solution-foods

Theme rank	Açaí	Avocado	Quinoa	Edible insects
Predominant frame	Superfood	Superfood	Superfood and solution	Solution
1 = most common theme	Health/wellness	Health/wellness	Health/wellness	Health/wellness
2	Environment	Food safety/quality	Food safety/quality	Taste
3	Food safety/quality	Environment	Environment	Environment
4	Promise/motivational	Promise/motivational	Taste	Food safety/quality
		Taste		
5	Taste	–	Acceptance	Food security
6	Acceptance	Acceptance	Power	Promise/motivational
	Power		Food security	
7	–	Power	–	Power
8 = least common theme	Food security	Food security	Promise/motivational	Acceptance

correlation of specific terms attributed to insect marketing, which was also found in marketing superfoods. The stories told in both frames are therefore very similar. However, as a look at the table also shows, some aspects gradually gain or lose weight as the frame alters. The more commonly the food is framed as a solution, the more often global issues such as food security are being marketed to consumers. We also observe that terms to describe the taste of a food often compare it to flavours assumed to be familiar to consumers. For insects, this tactic might materialize in the West because to date, many Western consumers express "distaste at the thought" of consuming insects (Evans et al. 2015, p. 298). Building on that, terms to increase acceptance often emphasize a food's traditional or ancient heritage, which follows the strategy of so-called 'nutritional primitivism' and is particularly prevalent in superfood marketing. In an attempt to romanticize indigenous food practices, marketers utilize consumers' perception that those foods are inherently healthier because they are simpler and more in touch with nature (Knight 2015). Mirroring this strategy, it is not a surprise that Acceptance terms are rarely used for marketing insects as exotic. The novelty of the food category would possibly undermine consumers' trust in insects' deliciousness and edibility. Interestingly, the theme Power is equally underrepresented in both frames. When present, nutritional qualities are discussed, which promise to empower consumers by providing a more healthy and energizing diet. However, insects' democratic potential, which derives from their ability to add value locally, is seldom mentioned. Rather, in both superfood- and solution-framed foods, the focus lies on promoting outstanding nutritional content, while assuring consumers about pureness, safety and standardisation of the food they consume. Environmental claims seem to appear as a common 'green' marketing strategy, by emphasizing organic and sustainable modes of production.

6 The Sustainable Superfood Frame

6.1 Can Markets Solve Social and Environmental Problems?

Reflecting on the results of our marketing claim study, it appears that the solution and superfood frames are not separate and conflicting. Instead, the frames have evolved into one that promotes insects as 'sustainable superfood' by emphasizing promises of global food security and environmental sustainability. Under this marketing agenda, insect products seemingly provide a solution to the many challenges the Earth is facing, while at the same time improving individual health and well-being, which seems to be the central theme of Western insect product marketing.

Lohmann (2006) warns that for some actors, such as businesses, institutions or governments, claiming that markets and products are a solution to negative externalities often remains as a strategy for creating a favourable public image and corporate profits, rather than truly fixing any of the externalities. It allows for 'business as usual'-mentality while leaving the difficult configuration of 'how' to achieve a positive impact for later. After all, the impression of solving externalities is at the core of markets for sustainable goods (Lohmann 2006), which are likely to 'discover' the next new "miracle superfood" (Haiken 2014) until the sustainability trend is exhausted. Further, a study conducted by Groeniger et al. (2017) suggests that consumption of often relatively highly priced superfoods remains for some consumers as an expression of status and social distinction from lower socioeconomic groups, rather than promoting 'health for everyone'. The extent to which sustainability is integrated into insects' double-frame therefore remains a question.

6.2 Two Pitfalls of Superfood Marketing

In order to realize insects' potential to be a more sustainable superfood, we suggest to avoid the two superfood-specific pitfalls, which insect promotion is currently employing: (1) *universalized sustainability and apolitical solutions,* and (2) *homogenization of diverse practices.* In the following section, the two pitfalls will be discussed and recommendations provided for how to achieve long term structural change towards sustainability.

6.2.1 Universalized Sustainability and Apolitical Solutions

As discussed throughout this paper, claims of insects' global solution potential are widely employed by a variety of actors, such as NGOs, IGOs, private companies, governments and research hubs (WUR 2014). As Yates-Doerr (2015) points out in her paper, FAO expresses the wish to create a "common vision" (FAO 2013, p. 3) through a common language and utilizes expressions such as "insects to feed the world" (WUR 2014) to promote insects' socio-economic and environmental potential. However, Yates-Doerr (2015) argues that this approach assumes a smooth, linear distribution of resources and ideas from one location to a shared, singular world. She states that 'the global', at least when addressing socioeconomic issues such as food security, cannot be approached with one universal approach. Instead, in the efforts to produce nutritional and gastronomic products, "edibility must be crafted in specific situations in response to the needs, regulations, and tastes of specific bodies and infrastructures" (Yates-Doerr 2015, p. 107).

Instrumentalizing sustainable superfood claims therefore frames insects as an attractive and 'easy' solution for the consumers to create a positive impact through their purchasing behaviour, advertising a clear conscience through consumption. This is not to say that the approach is necessarily wrong: consumer education is essential, and claims of insects being a global solution might make consumers reconsider and change their consumption patterns towards more sustainable ones. However, the claims of insects' ability to 'save the world' remind of the exaggerated health promises of superfood marketing. While they certainly help to catch consumers' attention, the example of açaí scams highlight the risk producers, businesses and consumers alike are exposed to if false promises become uncovered. This raises a concern about insects' potential to become a truly sustainable superfood, if they are framed as the solution to climate change issues while lacking concrete evidence of how exactly this is to materialize. For example Halloran et al. (2015) stress that there is not enough research yet confirming which social and environmental impacts might arise from the Western insect industry.

As emphasized earlier, the potential of insects to be a more sustainable superfood stems from the fact that their local potential allows their application in all sorts of contexts, exercised by all sorts of people (Müller et al. 2016). Instead of one globalized approach, which usually advertizes insect's ability to 'save the world', context-specific insect solutions should to be developed and marketed to a concerned set of actors, backed up by appropriate research evidence to demonstrate how value can be added locally (Müller et al. 2016).

6.2.2 Homogenization of Diverse Practices

In studying superfoods, it is uncovered that even though part of their attractiveness derives from their exotic origin, their application in Western products such as snack bars, smoothies, beauty products and even alcoholic drinks dismisses that a food item has a history of its own in the wider society in which it is rooted (Goffman 1971). The superfood phenomenon merely romanticizes the food's cultural origin and heritage, utilizing it as a marketing tactic, but quickly detaching the superfood from its original meaning and purpose (Loyer 2016).

Also in relation to insects, Yen (2016) warns that if diverse insect practices are becoming homogenized, the richness of different traditions and their meanings will be lost. He foresees that as legislating restrictions will continue to regulate interactions between the West and traditional insect eating communities, only a small number of species will be allowed for rearing in the West. Furthermore, only a limited number of species can be domesticated using Western production methods. Yen (2016) concludes that “in several generations' time, the domestic cricket and the mealworm may be classified as traditional Western insect food – yet they started off as either laboratory insects or as feed for pets and other animals.” (p. 68). Therefore, by continuing to market Western insects as superfoods, insect consumption is not likely to promote the natural diversity and cultural significance the different insect eating traditions originally have. Instead, homogenizing diverse practices could pose a threat to its multiplicity.

Ironically, by discussing the enormous insect category under the one umbrella term ‘edible insects’, also many of the arguments put forward in this paper are guilty of homogenization. So far, over 2000 edible species worldwide have been documented (Jongema 2015), even though the real number is likely to be considerably larger (Evans et al. 2015). By focusing mostly on a more technical view of insects as food, with an emphasis on farmed insects, global environmental impact, consumer acceptance, nutritional properties and the importance of upscaling production, Müller et al. (2016) detect that structural inequalities, justice, access and distribution are rarely considered. Therefore the edibility and sustainability potential in the West should be examined by taking into account the differences between species and local contexts in which they are to be applied to.

7 Conclusion and Recommendations of Sustainable Integration of Insects in Western Diets

To summarize, the purpose of this chapter was to explore the tensions arising from double-framing insects as both superfood and the solution to climate change and global health issues. We set out to explore these tensions by conducting a case-based, comparative analysis of three food items which are framed by media outlets as a ‘superfood’, contributing to the largely unexplored superfood field. We detected that externalities for superfoods tend to emerge as interaction between the West and traditional consumer and producer communities intensifies. By applying the knowledge gathered in the superfood study to current development of the Western insect sector, we concluded that insects are currently in Phase 1 of ‘superfoodization’, however differing in two major aspects that can help to avoid the similar, unsustainable path that many superfood-framed food items pursue. First, the yet missing interaction between the West and traditional insect eating communities means that Western insect industry will only add value locally and context-specifically in the West, but also that the negative externalities won’t reach the traditional insect eating communities to the same extent as with other superfoods. Second, the involvement of a diverse set of sustainability-driven actors during industry formation is likely to result in productive institutional logics that will guide the most suitable sustainability identity for the industry. These differences, we claim, have the potential to weaken the negative, superfood-specific pitfalls once the insect industry is scaled up.

We also discovered that superfood marketing tactics are effectively applied to marketing insect products in the West. Contrary to the initial suspicion, we find that solution and superfood frames are not two conflicting frames. Rather, the solution-narrative is a logical continuation of the superfood-frame, as the value of 'sustainability' has been uncritically added without addressing the 'how' of achieving long-term structural change. In that understanding, we contribute to the framing theory by testing how competing frames might cancel each other, reinforce existing values, or push in conflicting directions, and eventually increase motivation for more careful evaluations of the alternatives (Borah 2011) in the insect industry.

If insects continue to be marketed as sustainable superfoods, the institutions, organizations, businesses and individuals who employ these marketing tactics are guilty of reinforcing two superfood-specific pitfalls: *universalization of sustainability and offering of apolitical solutions*, and *homogenization of diverse practices*. We argue that these pitfalls are to be avoided in order for insects to become a 'truly sustainable' superfood. To tackle this, the main recommendation of this study is to further explore insects' potential to add value locally, as 'the global', at least when addressing socio-economic issues such as food security, cannot be approached with one universal approach (Yates-Doerr 2015). First, thorough scientific research of the context-specific environmental, social, economical and cultural impacts of insect farming in the West needs to be undertaken. Without impact assessment of insect rearing (Müller et al. 2016) or environmental management practices, insects' potential to positively contribute to sustainable food production, environmental conservation and improved livelihoods (Yen 2015) will remain largely unexplored. The research findings should then be applied to develop dynamic sustainability metrics that can help to measure and support claims of sustainability successes.

Another recommendation for avoiding the pitfalls is to explore which set of actors should be included in the discourse to ensure long-term sustainability of the Western industry. Because not one universalized definition of sustainability exists, it is important that the discourse stays open and robust so that the meaning of sustainability develops along the industry development. Additionally, to utilize insects' democratic potential, we recommend exploring which marginalized actors could benefit from the Western insect industry and how (Müller et al. 2016; Kaukua and Schiemer 2017).

Further, to avoid homogenization of the large category of edible insects, Yen (2016) urges to document traditional use of edible insects in as many cultures as possible before that information is lost, tackling the loss of natural biodiversity and cultural heritage. This way will insects as a food category, and not as a single food item, be fully appreciated and acknowledged.

But in order to achieve long-term sustainability, the knowledge must be transferred into actions, for example in form of education. Educating consumers about different meanings of sustainability in each local context will empower them to make responsible food choices. No food item is 'super' or a 'solution' in itself, but will only inherit these qualities in the hands of the markets. For this reason, it is impossible to answer universally whether edible insects are a truly sustainable food or not. Through our research, we have demonstrated that it is important to consider the local context, current market trends and the set of actors who would effectively benefit from the insect 'solution'. With our findings and recommendations, we hope to have shed light on opportunities and threats to insects' future sustainability performance, but also opened the door for configuring 'how' sustainability could be embedded not just in the Western insect sector, but in any upcoming food industry from early on.

References

Abrams A (2016) The impacts of marketing "nutrient powerhouses" on edge-dwellers. EnviroSociety. http://www.envirosociety.org/2016/05/superfoods-the-impacts-of-marketing-nutrient-powerhouses-on-edge-dwellers/. Accessed 5 Apr 2017

Aquiar F, Menezes V, Rogez H (2012) Spontaneous postharvest fermentation of acai (Euterpe Oleracea) fruit. Postharvest Biol Tec 86:294–299. https://doi.org/10.1016/j.postharvbio.2013.07.015. Accessed 7 Mar 2017

Banerjee S, Coussens NP, Gallat FX, Sathyanarayanan N, Skrikanth J, Yagi KJ, Gray SS, Tobe SS, Stay B, Chavasd LMG, Ramaswamaya S (2016) Structure of a heterogeneous, glycosylated, lipid-bound, in vivo-grown protein crystal at atomic resolution from the viviparous cockroach Diploptera Punctata. IUCrJ 3(4):282–293. https://doi.org/10.1107/S2052252516008903

Barrie J (2014) Our protein obsession is getting out of control. Munchies. https://munchies.vice.com/en_us/article/our-protein-obsession-is-getting-out-of-control. Accessed 20 Apr 2017

Blake I (2017) The 17 superfoods that are set to be 2017's hottest health food trends – from 'bacon flavored' red algae to edible insects. Daily Mail. http://www.dailymail.co.uk/femail/food/article-4105078/The-17-superfoods-set-2017-shottest-health-food-trends-bacon-flavoured-red-algae-edible-INSECTS.html#ixzz4eXQKmgCz. Accessed 15 Apr 2017

Blakely R (2014) Super-food of the future flies off the shelf. The Australian. http://www.theaustralian.com.au/news/world/superfood-of-the-future-flies-off-the-shelf/news-story/b2a2abee04ef683050f3518da681d02. Accessed 13 May 2017

Blythman J (2013) Can vegans stomach the unpalatable truth about quinoa? The Guardian. https://www.theguardian.com/commentisfree/2013/jan/16/vegans-stomach-unpalatable-truthquinoa. Accessed 14 Apr 2017

Blythman J (2016) Can hipsters stomach the unpalatable truth about avocado toast? The Guardian. https://www.theguardian.com/commentisfree/2016/aug/12/hispters-handle-unpalatable-truth-avocado-toast. Accessed 21 Jan 2017

Borah P (2011) Conceptual issues in framing theory: a systematic examination of a decade's literature. J Commun 61(2):246–263. https://doi.org/10.1111/j.1460-2466.2011.01539.x

Boskov-Hansen H (2017) Fødevarestyrelsen. Telephone interview. 5 Apr 2017, Copenhagen

Bourdieu P (1984) Distinction: a social critique of the judgement of taste. Harvard University Press, Cambridge

Bowler J (2016) Scientists think cockroach milk could be the superfood of the future. ScienceAlert. http://www.sciencealert.com/scientists-show-why-we-should-all-start-drinking-cockroach-milk. Accessed 16 Mar 2017

Brasileiro A (2009) Health craze deprives poor Brazilians of acai berries. Pittsburgh Post Gazette. http://www.post-gazette.com/food/2009/05/18/Health-craze-deprives-poor-Brazilians-of-acai-berries/stories/200905180. Accessed 05 May 2017

Brondízio E (2008) The Amazonian Caboclo and the açaí palm : forest farmers in the global market. Hum Ecol 38(2):319–320. https://doi.org/10.1007/s10745-009-9299-1

Business Call to Action (BCtA) (2015) SAMBAZON: providing sustainable forest management to Açaí fruit growers in the Brazilian Amazon Rainforest. Case Study. In: Business Call to Action. http://www.businesscalltoaction.org/wp-content/files_mf/bcta_case_study_sambazon_web.pdf. Accessed 20 Jan 2017

Callon M (1998) An essay on framing and overflowing: economic externalities revisited by sociology. In: Callon M (ed) The laws of the markets. Blackwell Publishers, London

CBI (2015) Product factsheet – superfoods in Europe. In CBI market intelligence ministry of foreign affairs. https://www.cbi.eu/sites/default/files/market_information/researches/product-factsheet-europe-superfoods-015_0.pdf. Accessed 10 Apr 2017

Criddle C (2016) Are superfoods losing their shine? The Telegraph Online. http://www.telegraph.co.uk/business/2016/10/02/are-superfoods-losing-their-shine/. Accessed 12 Apr 2017

Danish Technological Institute (DTI) (2017) inVALUABLE. https://www.dti.dk/specialists/invaluable/38118?cms.query=inValuable. Accessed 18 Apr 2017

DeFoliart G (1999) Insects as food: why the western attitude is important. Annu Rev Entomol 44(1):21–50. http://labs.russell.wisc.edu/insectsasfood/files/2012/09/20_WesternAttitude_savedReducedSetting.pdf. Accessed 3 Mar 2017

Dossey A, Morales-Ramos J, Rojas M (2016) Insects as sustainable food ingredients. Elsevier, New York

Druckman J (2001) The implications of framing effects for citizen competence. Polit Behav 23(3):225–256. https://doi.org/10.1023/A:1015006907312

Durst PB, Johnson DV, Leslie RN, Shono K (2010) Forest insects as food: humans bite back. Proceedings of a workshop on Asia-Pacific resources and their potential for development, February 19-21, 2008, Chiang Mai, Thailand. RAP Publication 2010/02. Food and Agriculture Organization of the United Nations Regional Office for Asia and Pacific, Bangkok. http://www.fao.org/docrep/012/i1380e/i1380e00.pdf. Accessed 10 Jan 2017

Entman R (1993) Framing: toward clarification of a fractured paradigm. J Commun 43(4):51–58. https://www.researchgate.net/profile/Robert_Entman/publication/209409849_Framing_Toward_Clarification_of_A_Fractured_Paradigm/links/0deec52e3d7f32deb3000000/Framing-Toward-Clarification-of-A-Fractured-Paradigm.pdf. Accessed 14 May 2017

Evans J, Alemu M, Flore R, Frøst M, Halloran A, Jensen A, Maciel-Vergara G, Meyer-Rochow V, Münke-Svendsen C, Olsen S, Payne C, Roos N, Rozin P, Tan H, van Huis A, Vantomme P, Eilenberg J (2015) 'Entomophagy': an evolving terminology in need of review. J Insect Food Feed 1(4):293–305. https://doi.org/10.3920/JIFF2015.0074

FAO (2013) The state of food and agriculture: food systems for better nutrition. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/018/i3300e/i3300e00.htm. Accessed 23 Jun 2017

FAO & CIRAD (2015) State of the art report on quinoa around the world in 2013. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/contents/b45ac696-e59e-4df7-84da-d2dce2fdded1/i4042e.pdf. Accessed 14 May 2017

Fleming A (2014) Do superfoods really exist? The Guardian. https://www.theguardian.com/lifeandstyle/2014/jan/16/do-superfoods-reallyexist-antioxidants. Accessed 09 Apr 2017

Gitlin T (1980) The whole world is watching: mass media in the making & unmaking of the new left. University of California Press, Berkeley

Goffman E (1971) Frame analysis: an essay on the organization of experience. Northeastern. University Press, Chicago. https://is.muni.cz/el/1423/podzim2013/SOC571E/um/E.Goffman-FrameAnalysis.pdf. Accessed 1 Mar 2017

Gonzalez Covarrubias J (2016) Forests, locals harmed in Mexico's avocado boom. Phys.Org Science. https://phys.org/news/2016-11-forests-locals-mexico-avocado-boom.html. Accessed 10 Apr 2017

Groeniger O, van Lenthe FJ, Beenackers MA, Carlijn BM, Kamphuis CBM (2017) Does social distinction contribute to socioeconomic inequalities in diet: the case of 'superfoods' consumption. Int J Behav Nut Phy 40(14):1–7. https://doi.org/10.1186/s12966-017-0495-x

Haiken M (2014) The next new miracle superfood: insects, scientists say. Forbes. https://www.forbes.com/sites/melaniehaiken/2014/07/11/the-next-new-miracle-superfoodinsects-scientists-say/#3e7dd74a3c95. Accessed 14 Apr 2017

Halloran A, Vantomme P, Hanboonsong Y, Ekesi S (2015) Regulating edible insects: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture. Food Sec 7(3):739–746. https://doi.org/10.1007/s12571-015-0463-8

Hamilton L M (2014) The quinoa quarrel. Who owns the world's greatest superfood? Food and environment reporting network (FERN). https://thefern.org/2014/10/quinoa-quarrel/. Accessed 12 Apr 2017

Hancock RD, Mcdougall GJ, Stewart D (2007) Berry fruit as 'superfood': hope or hype? Biologist 54(2):73–79. https://www.researchgate.net/publication/290856845_Berry_fruit_as_%27superfood%27_Hope_or_hype. Accessed 2 Feb 2017

House J (2016) Consumer acceptance of insect-based foods in the Netherlands: academic and commercial implications. Appetite 107:47–58. https://doi.org/10.1016/j.appet.2016.07.023

Jacobsen SE (2011) The situation for quinoa and its production in Southern Bolivia: from economic success to environmental disaster. J Agron Crop Sci 197(5):390–399. https://doi.org/10.1111/j.1439-037X.2011.00475.x

Jockers D (2012) The anti-ageing superfood avocado. Natural News. http://www.naturalnews.com/035763_avocado_superfood_anti-aging.html. Accessed 10 Apr 2017

Jones J (2012) The protein myth: why you need less protein than you think. http://www.huffingtonpost.com/jessica-jones-ms-rd/protein-diet_b_1882372.html. Accessed 10 June 2017

Jongema Y (2015) List of edible insects of the world. Wageningen University and Research. Wageningen. http://tinyurl.com/mestm6p. Accessed 10 Jan 2017

Kasterine A (2016) Quinoa isn't a threat to food security. It's improving Peruvian farmers' lives. The Guardian. https://www.theguardian.com/sustainable-business/2016/jul/17/quinoa-threat-food-security-improving-peruvian-farmers-lives-superfood. Accessed 07 Apr 2017

Kaukua P, Schiemer C (2017) Edible insects: solution-food or superfood? Master thesis, Copenhagen Business School. Unpublished

Kelemu S, Niassy S, Torto B, Fiaboe K, Affognon H, Tonnang H, Maniania MK, Ekesi S (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insect Food Feed 1(2):103–119. https://doi.org/10.3920/JIFF2014.0016

Kerssen T (2015) Food sovereignty and the quinoa boom: challenges to sustainable re-peasantisation in the southern Altiplano of Bolivia. Third World Q 36(3):489–507. https://doi.org/10.1080/01436597.2015.1002992

Khazan O (2015) The selling of the avocado – how the "alligator pear" went from obscure delicacy to America's favorite fruit. The Atlantic. https://www.theatlantic.com/health/archive/2015/01/the-selling-of-the-avocado/385047/. Accessed 13 Apr 2017

Kimball W (2015) The rise and fall of superfoods. Hopes and Fears. http://www.hopesandfears.com/hopes/city/food/213413-myth-superfoods-acai-quinoa-chia-goji. Accessed 10 Apr 2017

Kingsley M (2015) Superfruit stars: where are they now? Acai, goji, and pomegranate. Nutritional Outlook. http://www.nutritionaloutlook.com/herbs-botanicals/superfruit-stars-where-are-they-nowacai-gogi-and-pomegranate. Accessed 09 Apr 2017

Knight C (2015) We can't go back a hundred million years. Food Cult Soc 18(3):441–461. https://doi.org/10.1080/15528014.2015.1043107

Kugel S (2010) Açaí, a global super fruit, is dinner in the Amazon. The New York Times. http://www.nytimes.com/2010/02/24/dining/24acai.html. Accessed 11 Jan 2017

Lohmann L (2006) 'Made in the USA' – a short history of carbon trading. In: Hällström N, Nordberg O, Österbergh R (eds) Carbon trading – a critical conversation on climate change, privatization and power. The Dag Hammarskjöld Centre, Uppsala. http://www.thecornerhouse.org.uk/sites/thecornerhouse.org.uk/files/carbonDDlow.pdf. Accessed 20 Jan 2017

Loyer J (2016) The social lives of superfoods. PhD thesis, University of Adelaide. http://hdl.handle.net/2440/101777. Accessed 29 Mar 2017

Lyon S (2015) Fair trade and indigenous communities in Latin America. In: Raynolds L, Bennett E (eds) Handbook of research and fair trade. https://www.researchgate.net/publication/276268582_Fair_Trade_and_Indigenous_Peoples_in_Latin_America. Accessed 29 Apr 2017

Manuell R (2016) Global edible insect market: trends & future prospects. New Food. https://www.newfoodmagazine.com/27056/news/industry-news/edible-insects-future/. Accessed 29 Apr 2017

Mills E (2016) Why your avocado toast could be destroying Mexican forest. The Telegraph. http://www.telegraph.co.uk/food-and-drink/news/why-your-avocado-toast-could-be-destroying-mexican-forests/. Accessed 19 Apr 2017

Mintel (2016) Super growth for "super" foods: new products development shoots up 202% globally over the past five years. http://www.mintel.com/press-centre/food-and-drink/super-growth-for-super-foods-new-product-development-shoots-up-202-globally-over-the-past-five-years. Accessed 14 May 2017

Mintel Group Ltd (2016) Food & drink trends 2017. http://www.mintel.com/global-food-and-drink-trends. Accessed 10 Apr 2017

Müller A, Evans J, Payne CLR, Roberts R (2016) Entomophagy and power. J Insect Food Feed 2(2):121–136. https://doi.org/10.3920/JIFF2016.0010

Muston S (2015) Our growing appetite for avocados is endangering their existence. The Independent. http://www.independent.co.uk/life-style/food-and-drink/features/our-growing-appetite-for-avocados-is-endangering-their-existence-10233525.html. Accessed 08 May 2017

Oonincx D, de Boer I (2012) Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS One 7(12):e51145. https://doi.org/10.1371/journal.pone.0051145

Orenstein J (2016) How the internet became ridiculously obsessed with avocado toast. Washington Post. https://www.washingtonpost.com/news/wonk/wp/2016/05/06/how-the-internet-became-ridiculously-obsessed-with-avocado-toast/?utm_term=.404d5498ba74. Accessed 12 Apr 2017

Pantsios A (2015) Are insects the next climate-friendly superfood? EcoWatch. http://www.ecowatch.com/are-insects-the-next-climate-friendly-superfood-1882022707.html. Accessed 14 Apr 2017

Payne CLR, Scarborough P, Rayner M, Nonaka K (2015) Are edible insects more or less 'healthy' than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over- and undernutrition. Eur J Clin Nutr 70:285–229. https://doi.org/10.1038/ejcn.2015.149

Pegler L (2015) Peasant inclusion in global value chains: economic upgrading but social downgrading in labour processes? J Peasant Stud 42(5):929–956. https://doi.org/10.1080/03066150.2014.992885

Ramos-Elorduy J (2009) Anthropo-entomophagy: cultures, evolution and sustainability. Entomol Res 39(5):271–288. https://doi.org/10.1111/j.1748-5967.2009.00238.x

Randels S, Laasch O (2016) Theorising the normative business model. Organization & Environment 29(1):53–73. https://doi.org/10.1177/1086026615592934

Reuteman R (2011) Superfruits — super sales and super claims. CBCN. http://www.cnbc.com/id/42933056. Accessed 09 Apr 2017

Rumpold B, Schlüter O (2013) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57(5):802–823. https://doi.org/10.1002/mnfr.201200735

Saner E, Morales M (2015) Ripe and ready: how 'evil geniuses' got us hooked on avocados. The Guardian. https://www.theguardian.com/lifeandstyle/2015/nov/02/avocados-ripe-ready-evil-geniuses-hooked. Accessed 13 Apr 2017

Shearman S (2014) Quinoa, chia seeds and kale: superfoods or supermarketing? The Guardian. https://www.theguardian.com/media-network/media-network-blog/2014/oct/02/quinoa-chia-seeds-kale-superfoods-marketing. Accessed 15 Mar 2017

Smith LC (2012) The "whole foods" paradox. Food Sovereignty, Eco-Iconography, and Urban Indigenous Discourse Indigenous Peoples and the Environment (2):59–77. https://doi.org/10.4000/elohi.288

Stehfest E, Bouwman L, Van Vuuren D, Den Elzen M, Eickhout B, Kabat P (2009) Climate benefits of changing diet. Clim Chang 95:83–102. https://doi.org/10.1007/s10584-008-9534-6

Steinfeld H (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/010/a0701e/a0701e00.HTM. Accessed 02 Apr 2017

Stone D (2015) Thanks to America, we've reached the peak avocado. National Geographic. http://theplate.nationalgeographic.com/2015/05/05/thanks-to-america-weve-reached-peak-avocado/. Accessed 22 Mar 2017

SuperfoodBlog (2017) http://superfoodblog.co.uk. Accessed 02 Apr 2017

The Oxford Dictionary (2016) Superfood – definition. https://en.oxforddictionaries.com/definition/superfood. Accessed 12 Apr 2017

United Nations Development Programme (UNDP) (2015) Human development report 2015. UNDP, New York. http://hdr.undp.org/sites/default/files/2015_human_development_report.pdf. Accessed 11 Apr 2017

Van Allen J (2014) Protein: why it's so popular right now. The Washington Post. https://www.washingtonpost.com/lifestyle/wellness/protein-the-nutrient-dujour/2014/07/22/6a11b882-0b7b-11e4-b8e5-d0de80767fc2_story.html?utm_term=.075b56e73f29. Accessed 19 Mar 2017

Van Huis A (2016) Edible insects are the future? P Nutr Soc 75(03):294–305. https://doi.org/10.1017/S0029665116000069

Van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects: future prospects for food and feed security. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/018/i3253e/i3253e.pdf. Accessed 28 Apr 2017

Vantomme P, Münke C, Van Huis A, Van Itterbeeck J, Hakman A (2014) Insects to feed the world conference. Summary report. Food and Agriculture Organization of the United Nations (FAO), Italy and Wageningen University and Research (WUR), Wageningen. http://tinyurl.com/p9dlnhg. Accessed 19 Mar 2017

Vos I (2016) Annual quinoa imports into European Union exceed 20.000 tons in February 2016. Mercadero. http://mercadero.nl/annual-quinoa-imports-into-european-union-exceed-20000-tons-in-february-2016/. Accessed 19 Apr 2017

Wageningen University and Research (WUR) (2014) Conference: insects to feed the world. https://www.wur.nl/en/show/Conference-Insects-to-feed-the-world.htm. Accessed 24 Jun 2017

Watson E (2013) Surfing, super fruits and social justice: Sambazon and the genesis of an Amazonian superfood empire. Foodnavigator USA. http://www.foodnavigator-usa.com/Manufacturers/Surfing-super-fruits-and-social-justice-Sambazon-and-the-genesis-of-an-Amazonian-superfood-empire?utm_source=copyright&utm_medium=OnSite&utm_campaign=copyright. Accessed 19 Mar 2017

Weisbaum H (2010) Acai berry scam: you'll lose money, not weight. NBCNews. http://www.nbcnews.com/id/38958053/ns/business-consumer_news/t/acai-berry-scam-youll-lose-money-not-weight/#.WU1iEVJ7HEY. Accessed 19 Jun 2017

Wepman M, Wepman W (2009) Quinoa: the miracle grain. Macrobiotics Today. http://www.encognitive.com/files/Quinoa:%20The%20Miracle%20Grain.pdf. Accessed 14 Mar 2017

Yates-Doerr E (2015) The world in a box? Food security, edible insects, and one world, one health collaboration. Soc Sci Med 129:106–112. https://doi.org/10.1016/j.socscimed.2014.06.020

Yen AL (2015) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insect Food Feed 1(1):33–55. https://doi.org/10.3920/JIFF2016.0011

Yen AL (2016) What is traditional? J Insects as Food Feed 2(2):67–68. https://doi.org/10.3920/JIFF2016.x002

Part VI
Insects as Animal Feed

Small-Scale Fly Larvae Production for Animal Feed

Marc Kenis, Bawoubati Bouwassi, Hettie Boafo, Emilie Devic, Richou Han, Gabriel Koko, N'Golopé Koné, Gabriela Maciel-Vergara, Saidou Nacambo, Sètchémè Charles Bertrand Pomalegni, Martin Roffeis, Maureen Wakefield, Fen Zhu, and Elaine Fitches

M. Kenis (✉) · S. Nacambo
CABI, Delémont, Switzerland
e-mail: m.kenis@cabi.org

B. Bouwassi · G. Koko
Fish for Africa-Ghana, Accra, Ghana

H. Boafo
CABI, Accra, Ghana

E. Devic
Entofood Sdn Bhd, Kuala Lumpur, Malaysia

R. Han
Guangdong Institute of Applied Biological Resources, Guangzhou, Guangdong, China

N. Koné
Institut d'Economie Rurale, Centre Régional de Recherche Agricole de Sotuba, Bamako, Mali

G. Maciel-Vergara
Department of Plant and Environmental Sciences, University of Copenhagen, Frederiksberg C, Denmark

S. C. B. Pomalegni
Institut National des Recherches Agricoles du Bénin, Cotonou, République du Bénin

M. Roffeis
KU Leuven, Department of Earth and Environmental Sciences, Division of Forest, Nature and Landscape, Leuven, Belgium

M. Wakefield
Fera Science Ltd, York, UK

F. Zhu
Huazhong Agricutural University, Wuhan, Hubei Province, People's Republic of China

E. Fitches
Fera Science Ltd, York, UK

Department of Biosciences, University of Durham, Durham, UK

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_15

Abstract Two fly species, the black soldier fly, *Hermetia illucens*, and the house fly, *Musca domestica*, are presently being promoted and used as feed for monogastric animals. Various production systems are being developed in different contexts and regions, from very small-scale used by smallholder farmers to industrial scale production factories. This chapter reviews the information available on production methods for the two fly species, with a focus on small-scale production systems. Larvae of both fly species can be produced either by exposing substrates to attract naturally occurring flies, or by breeding adults to obtain eggs that will be placed on the larval rearing substrates. The two fly species are compared with respect to performance, user-friendliness, safety and sustainability. The advantages and disadvantages associated with rearing these species in different situations and perspectives are highlighted. This chapter also discusses knowledge gaps and provides recommendations for production and suggestions for further research.

1 Introduction

Insects are increasingly proposed as a component of feed for monogastric animals such as poultry and fish, as a replacement for conventional protein sources that are becoming increasingly expensive and considered unsustainable (van Huis 2013; van Huis et al. 2013; Makkar et al. 2014). Fly larvae are particularly recommended for this purpose because they contain a high amount of animal protein (Makkar et al. 2014) and because they can be produced rapidly and at low costs on organic wastes (Diener et al. 2011a; van Huis 2013; Kenis et al. 2014, Pastor et al. 2015). The two main fly species used for animal feed are the black soldier fly (*Hermetia illucens* (L.) – Diptera: Stratiomyidae) and the house fly (*Musca domestica* L. – Diptera: Muscidae). Industrial fly larval production units are presently being developed worldwide, in particular for black soldier flies (Drew and Pieterse 2015; Pastor et al. 2015) but detailed information on methods is rarely available because none of the companies have to date published details of their production systems. Patents are available, but they are not particularly useful as they are not peer-reviewed and they do not provide detailed information or indicators of performance. The main challenges in industrial production systems are technological rather than biological. Fly larvae, however, can also be produced at a smaller scale in individual farms or in simple production systems for local utilisation as poultry or fish feed (Caruso et al. 2014; Kenis et al. 2014; Koné et al. 2017; Nyakeri et al. 2017). Such small and medium-scale systems are particularly suitable for developing countries, where farmers cannot easily access or pay for protein feed and manpower is not expensive (van Huis et al. 2013).

This review covers published information on small– and medium-scale fly production systems for animal feed worldwide. It does not cover industrial systems or fly production systems for other purposes (e.g. sterile insect technique) or laboratory rearing techniques. Information on other aspects of the use of fly larvae as animal feed are also excluded, e.g. nutrition, health and safety, etc., unless it is directly relevant for the production system. Although blow flies (Calliphoridae) are also occasionally considered for animal feed (Yehuda et al. 2011), published information on production systems was found almost exclusively on black soldier fly and house fly. Therefore, this review will focus on these two species.

2 Black Soldier Fly, *Hermetia illucens*

Black soldier fly (BSF) is currently the fly species whose larvae are most commonly used for animal feed in medium- and large-scale production systems. Several companies are producing larvae worldwide but their techniques are usually not published. The most comprehensive publication on a medium-scale BSF production system is that of Caruso et al. (2014) who detail a BSF system developed in Indonesia based on palm kernel meal. Other published general descriptions include Sheppard et al. (2002) who developed the first methods for continuous rearing of BSF, the report by Newton et al. (2005) on the use of BSF for the management of swine manure and various how-to guides such as those of Bullock et al. (2013) and Park (2016). In 2017, Nyakeri et al. published data on a simple system developed in Kenya. Pastor et al. (2015), in their review on conversion of organic wastes into fly larval biomass, also review BSF rearing systems and provide lists of relevant patents. Cortes Ortiz et al. (2016) provide a review of important features for BSF rearing. PhD theses such as those of Barry (2004) and Gobbi (2012) may also provide important unpublished information on BSF production systems.

BSF production systems can be separated into two categories. The first systems developed since the 1970s consisted of exposing substrates to naturally occurring BSF females for laying eggs. While these are still used for individual farmers, hobby gardeners or hobby pet breeders, nowadays, most systems, in particular medium- and large-scale ones, are based on a separate adult rearing system for egg production.

2.1 Systems Based on Natural Oviposition

The exposure of substrates to attract naturally occurring BSF females was the first system developed to produce BSF. Although not considered reliable enough for sustaining regular BSF larvae production and waste recycling, it can still be considered for small-scale farmers or home gardeners in regions where BSF naturally occurs at high densities. The first to develop such systems were Sheppard, Newton and colleagues in Southern USA (Sheppard et al. 1994; Newton et al. 2005). The system used concrete basins built directly under caged layers or swine. BSF populations were first artificially increased through the importation of adults collected in the surrounding area, but then populations became self-reproducing. Harvesting was based upon the self-migratory behaviour of pre-pupae which exited the rearing

Fig. 1 Natural oviposition system for black soldier fly in Ghana (Photo: M. Kenis)

basins naturally. Pupation took a minimum of 10 days so collected pre-pupae could be stockpiled prior to processing or utilization. It was estimated that theoretically, in a 5-month season, when BSF are most abundant, a 100,000 bird caged layer house could produce 53 tonnes of pre-pupae suitable for feed (Newton et al. 2005).

Since then, many simple designs based on the same principle have been proposed, following similar procedures: (1) establishment of a sustainable BSF population at the production site; (2) exposure of substrates such as manure, food and market waste, agro-industrial waste or other organic waste; and (3) self-migration of pre-pupae into a collecting container (see, e.g. Bullock et al. 2013; Rana et al. 2015; Park 2016) (Fig. 1). Many descriptions and videos of systems can also be found on the internet. However, to our knowledge, none of these self-sustaining production systems have been accurately tested and compared for their performances. An exception is the 2017 study by Nyakeri et al. who developed, described and assessed such a system in Kenya. Feeding containers of 1 m × 0.5 m × 0.5 m were half filled with four types of waste and replenished twice a week. Corrugated flexible plastic tubes placed on the substrates were used as an oviposition medium. Mash maize grain was the most effective substrate, providing a yield of over 3 kg of fresh larvae/month, followed by vegetable remains, fish remains and animal manure. In Guinea, Hem et al. (2008) used simple iron tanks, roofed and covered by chicken wire, and filled with palm kernel meal mixed with water (1 kg for 2 L of water) to obtain BSF pre-pupae used to feed tilapia. Larvae were collected after 4 weeks by filtering and cleaning with water. Eight tanks each containing 80 kg of dry palm kernel meal were used and the weekly yield was 30 kg of fresh larvae.

The main issue with the natural oviposition system in BSF is that the containers have to be regularly emptied of the rotten compost (Nyakeri et al. 2017), which causes delays in production as the egg-prepupal period takes at least 3 weeks.

A solution would be to have several rearing units and for cleaning to occur on a rotational basis. Furthermore, depending on the local climate, natural oviposition may only occur at restricted periods of time during the year. It also implies that BSF are abundant at the site and, when this is not the case, populations need to be built up, for example by releasing pupae from the production system. Finally, in these systems, it is always the migrating pre-pupae that are collected whereas feeding larvae used for animal feeding might be more digestible because they contain less chitin (Newton et al. 2005).

2.2 Systems Based on Adult Rearing and Egg Production

Most BSF production systems involve an adult rearing system for egg production and, thus, include two separate units: one for the maintenance of the breeding colonies in captivity (cages, greenhouses or rearing rooms) and one for the growth of the larvae (trays, bays, digesters, etc.) (Newton et al. 2005; Caruso et al. 2014; Diener et al. 2015). Adult rearing and egg production is probably the most critical stage in the development of a successful BSF production system. It requires specific expertise and is therefore not advised for use by farmers who cannot devote a significant part of their time to BSF production. Nevertheless, small-scale systems with adult rearing can be envisaged when staff are available for the maintenance of the rearing. For example, a successful BSF production system was developed by the PROteINSECT project at the experimental farm of the NGO Fish for Africa in Accra, Ghana, in collaboration with the University of Stirling, UK (Devic et al. 2014; Charlton et al. 2015). An alternative approach to provide the expertise needed for adult rearing would be to centralise egg production in a factory that would then distribute neonate larvae to numerous small-scale larvae production units. This system has been proposed by Diener et al. (2015) whose overarching aim was to decentralise organic waste treatment with BSF.

Even with expertise, oviposition performances obtained in present rearing systems are still very far from the optimum (e.g. ca. mean 14–35 eggs/female in Gobbi (2012)) and it is still not totally clear how fecundity in production systems can be improved. On average, BSF females lay 320–620 eggs each, with some females being able to lay up to 1235 eggs (Pastor et al. 2015 and references therein).

Adult biology and rearing methods are described in Cortes Ortiz et al. (2016). Adults live only a few days during which time they do not feed. Therefore, food is not necessary, but water is essential and has to be provided through a water dispenser and/or by spraying the cage walls, especially during dry days. However, Rachmawati et al. (2010) reported that egg production is more effective when adults are fed with a solution of 5% honey in water. Mating usually occurs between 2-day old females and slightly older males, and oviposition occurs in one single clutch about 2 days later (Tomberlin and Sheppard 2002; Cortes Ortiz et al. 2016). This is important when managing a colony since mating success can be jeopardized by older males or females.

Light is essential for adult mating and oviposition (Tomberlin and Sheppard 2002; Cortes Ortiz et al. 2016). Natural light is preferred, e.g. in large greenhouses (Sheppard et al. 2002; Barry 2004; Caruso et al. 2014), but adequate artificial light conditions have been described by Zhang et al. (2010) and Gobbi (2012). The main issue with a "greenhouse" system is that it is more difficult to maintain a stable, favourable environment for adults than in a room with controlled environmental conditions. Indeed, BSF adults are best reared at 27–30 °C and 70% RH (Tomberlin et al. 2009; Zhang et al. 2010; Holmes et al. 2012). Thus, the actual tendency in new, large BSF production systems is to produce eggs indoors under artificial light in controlled environments (Pastor et al. 2015). This is, however, difficult to achieve in small production units.

The ideal adult density for egg production will vary according to the size of the cage/rearing room (Gobbi 2012). Cages should preferably be large (at least 2 m^3 but Barry (2004) mentions 66 m^3) because adults start mating in flight, however reasonable egg production is also obtained in cages as small as 40 cm × 40 cm × 40 cm if light conditions are suitable. Some plants (real or artificial) in cages favour mating because they serve as a *lekking* location (Tomberlin and Sheppard 2001). Lekking is a mating behavior exhibited by the males of a species, where they congregate in certain areas and "call" to the females of the species (Bullock et al. 2013).

Oviposition devices usually consist of a layer of attractant substrate (manure, fermented or decomposing organic material/wastes) topped with a dry support offering numerous crevices (e.g. cardboard strips or dry leaves) for egg laying. Contact between the wet substrate and the dry support should be avoided. However, the eggs should remain in a humid environment (humidity is provided by the wet substrate) to avoid desiccation. Eggs can be harvested by collecting the dry support. The number of eggs is then assessed by separating the clutches from the oviposition support, followed by weighing the total amount collected or by using a standard support with a known weight.

The fecundity obtained in a production system also depends on the fitness of the adults at emergence, which again depends upon the pupae production system. Larval diet affects not only the larval cycle and mortality (see Sect. 2.3 below) but also adult size and fecundity (Nguyen et al. 2013; Gobbi et al. 2013). Temperature and humidity during the larval and pupal stages also affect adult fitness (Tomberlin et al. 2009; Holmes et al. 2012). Finally, the quality of pupation substrates may also affect pupal and adult emergence (Holmes et al. 2013). For these reasons, the BSF rearing stock for the production of adults is often separated from the regular larval production system (see Sect. 2.6 below).

2.3 Larval Growth

Eggs, when collected from adult rearing cages, are not always placed directly in the larval rearing container but first in a small hatching vessel for 6–7 days to allow the eggs to hatch and the young larvae (=seed larvae) to start growing (Caruso et al. 2014).

The nursery vessel is a container (box, bowl, etc.) filled with a 3–5 cm substrate layer and covered with gauze to prevent competitors and predation. This nursery stage is not compulsory, but worthwhile for several reasons: (1) it provides optimal conditions for eggs hatching and for the new-born larvae to start their development; (2) it reduces the chances for other fly species to colonise the larval feeding substrate during the first days of development; (3) it reduces the occupation time of the rearing trays and, thus, the space required for the larval production. Eggs are highly sensitive to humidity and direct contact with water must be avoided.

Following the nursing period, seed larvae are transferred to culture trays, bays or digesters, containing a moist nutritious substrate. Larvae will feed and grow in these structures for several days. BSF larvae are able to feed on many organic wastes. Many authors have tested substrates for their performance. Pastor et al. (2015) reviewed the literature on substrates tested for BSF production including consideration of egg and larval inoculum optimal densities, as well as larval yield (when available). Most authors tested only one substrate, which makes the comparison of substrates in different systems and conditions very difficult. Exceptions include the substrate tests made by Gobbi et al. (2013), Barry (2004), Kalova and Borkovcova (2013) and Diener et al. (2011a, b), and the comparison between poultry and swine manure by Newton et al. (2005). In general these tests showed that the BSF is able to accept a wide spectrum of wastes of both plant and animal origins. Yields, however, are extremely variable depending on the production unit, the region, and the substrate. In Ghana, the PROteINSECT small-scale production system produced, on average and depending on substrate, between 18 and 115 g of dried larvae per kg of dry substrate with the dried larvae weighing about four times less than fresh larvae.

Density, temperature, and humidity also influence larval growth performance and survival. The optimal density of larvae may vary depending on the substrate, thus, optimal amount of eggs to inoculate a kg of substrate cannot be generalised. Caruso et al. (2014) used 134 mg eggs for 1 kg of dry palm kernel meal whereas 30–40 mg eggs were used to inoculate 1 kg of dry substrate in Ghana (Devic et al. 2014). BSF larvae grow optimally at temperatures ranging between 27 and 30 °C and in a substrate of 60–90% humidity (Sheppard et al. 2002; Tomberlin et al. 2009). However, Pastor et al. (2015) suggested that these parameters should be adjusted to optimise the production efficiency and energy consumption of mass-rearing systems. Low temperatures (<19 °C) are also not recommended for BSF as they lead to reduced performance and mortalities (Holmes et al. 2016). Mortality is known to occur when the temperature in the substrate becomes too high, due to larval feeding activity. Therefore, metal containers (which allow the heat to escape) are preferred over plastic containers. BSF does not grow well in any substrate with stagnant water and tend to escape thanks to the capacity of the body to adhere on the containers walls when the humidity is high. Thus, depending on the substrate used, a system draining leachates out of the rearing containers may be necessary. Finally, the depth of the substrate should preferably not be more than 10–15 cm as the bottom part may become anoxic.

2.4 Larval/Prepupal Extraction

When the larvae have reached the desired size, they are separated from the feeding substrate. The easiest separation method takes advantage of the migratory behaviour of pre-pupae and simply lets the pre-pupae egress naturally from the substrate. Various systems can be implemented to allow pre-pupae to crawl out from substrates using side ramps (15–30°) in rearing containers (Sheppard et al. 1994; Newton et al. 2005). However, extracting larvae at the end of their feeding stage is often preferred due to their lower chitin content, increasing digestibility for animal nutrition (Newton et al. 2005). In addition, extracting larvae rather than pre-pupae has the advantage of gaining time in the production rotation because larvae can be collected several days before the pre-pupae at about the same weight. It must be said that, while most industrial production systems nowadays harvest larvae rather than pre-pupae, the harvesting technology is usually kept secret. Possibilities include, e.g. (1) heating bottom trays with hot water pipes resulting in the larvae crawling out using side ramps; (2) increasing water content of the substrate, which also induces larvae crawling out using side ramps; (3) pouring tray contents on a sieve placed under strong light, inducing the photophobic larvae to pass through the sieve (Pastor et al. 2015). In small- and medium-scale systems various types of sieving systems can be used (Caruso et al. 2014). These will greatly depend on the substrates, i.e. some substrates can be placed directly on a sieve and larvae will pass through, while others will require more active sieving and cleaning.

2.5 Killing and Drying

After being left without food and water for 24 h for purging of gut contents, larvae (or pre-pupae) can be directly fed to farmed animals. For feeding young chicks or small fish, it would be recommended to collect and use the larvae at a smaller size. Larvae can be kept alive at 4 °C, in physiological dormancy, for several months without pupating (Caruso et al. 2014). Nevertheless, in most cases, larvae that are not used immediately will be killed and dried prior to inclusion into animal diet. Remarkably few data are found in the literature on methods to kill and dry specifically BSF larvae or pre-pupae, however, the methods do not differ much from those used for insects for feed and food in general (van Huis et al. 2013). In small and medium-scale systems, larvae can be killed in a freezer or in boiled water, and dried in an oven or microwave. In small systems in the tropics, where the use of an oven may not be economically viable, larvae can be dried in the sun, but it will take longer than smaller larvae such as house fly larvae. In Indonesia, sun drying required 17 h of sunshine with a light intensity >20,000 Lux, a temperature of 38 ± 4 °C and a air humidity of 47 ± 6% (Caruso et al. 2014). Solar dryers can be used, e.g. with an air flow run by a solar panel

Fig. 2 Solar dryer used to dry fly larvae in Ghana (Photo: M. Kenis)

(Fig. 2), but larvae should first be killed by being placed in boiling water for a few seconds. The drying may take up to 3 days (Authors, unpublished data). Caruso et al. (2014) provide a drying system using a homemade oven with a small electric heater and a closed wooden structure. When dry (i.e. less than 10% moisture), larvae should be ground before being included in animal feed.

2.6 Adult Production

The production of BSF pre-pupae is required for adult rearing (see Sect. 2.3 above). Pre-pupae may come from the regular production system or from a separate system but performant substrates and conditions are required to produce adults with high fitness. Since feed shortage or malnutrition reduce fecundity, it is essential to allow the larvae to feed properly until they become pre-pupae. These can then be collected using their migratory behaviour. Pre-pupae can be placed in sawdust to pupate, preferably in a container protected from prepupal and pupal parasitoids (puparia), which have the potential to decimate BSF populations (Bradley et al. 1984; Devic and Maquart 2015). Pupae must be kept in a humid environment but protected from direct contact with water. Adults are either transferred regularly from the pupation container into the adult cages or puparia can be directly placed in the cages a few days before emergence.

2.6.1 House Fly, *Musca domestica*

Compared to BSF, the house fly (HF) has been studied far longer and its biology and ecology have long been known (e.g. Hewitt 1914; West 1951). However, although HF are very suitable for use in animal feed (Kenis et al. 2014; Makkar et al. 2014) and production methods are available, there are currently less worldwide initiatives to produce HF as compared to BSF – except in China; this is probably because of the negative reputation of the HF as a vector of animal and human diseases (Greenberg 1973; Axtell and Arends 1990).

Only a few publications propose the description of full HF production systems. A comprehensive work is that of a joint project conducted by the University of Alicante, Spain, and the Institute of Zoology of the Slovak Academy of Sciences in Bratislava, Slovakia, that developed HF production systems in Spain and Slovakia based on pig manure (Čičková et al. 2012a, b, 2013; Pastor et al. 2011, 2014). Roffeis et al. (2015) later used their data to carry out an environmental life cycle assessment based on these systems. Other data have been published in China, but full systems are rarely described, with the exception of Wang et al. (2013), who present a system focusing mainly on swine manure reduction, and Cortes Ortiz et al. (2016) describing a system based on poultry manure. Many patents exist in China for HF production, but they usually only concern technical details, are often unintelligible (at least when translated into English) and are not fully reliable as they have not been peer reviewed and performances have not been published. In Africa, the HF is commonly used by farmers as poultry feed (Pomalégni et al. 2016, 2017) and has often been tested for its nutritional quality, but there are few publications on rearing techniques (Kenis et al. 2014; Koné et al. 2017). The largest producers have never published details of their techniques (Drew and Pieterse 2015).

Similarly to BSF, HF production systems can be classified into two categories. Firstly, the larval production that relies on natural oviposition, i.e. substrates, are exposed and females are naturally attracted to lay eggs. This technique is suitable for small production systems, e.g. on farms, in tropical regions where HF are available the whole year. Secondly, adults can be reared in cages or confined rooms to produce eggs which are then inoculated in a substrate suitable for larval development. This system is most appropriate for industrial scale production, but individual farmers also use it, particularly in China.

2.7 Larvae Production Based on Natural Oviposition

The technique of obtaining larvae from substrates exposed to naturally-occurring flies is mainly known from Sub-Saharan Africa, but also West Africa, where house flies are available in abundance the whole year round. Several studies assessing the suitability of HF larvae as animal feed in West Africa have obtained larvae by freely exposing various attractive substrates (see a list of these studies in Kenis et al. 2014). However, very little was known on the actual use of HF larvae on farms until

Fig. 3 Maize bran exposed to house flies for larvae production in a village in Benin (Photo: IFWA)

Pomalégni et al. (2016, 2017) showed that nearly 6% of the indigenous poultry farmers in Benin ($n = 960$) produce HF larvae, at least occasionally for their poultry (Fig. 3). HF larvae are produced by exposing substrates, usually organic wastes, in containers around farms to attract naturally occurring flies. Larvae are extracted from the substrate 3–5 days later using sieves, and then given directly to the poultry. Beninese farmers cited at least 28 substrates used to produce larvae, the most commonly cited being soy and maize bran, as well as pig and chicken manure (Pomalégni et al. 2017). This study also showed that farmers using HF as a source of protein tended to have a higher income from poultry farming, a higher level of education, and a larger flock than those that did not use HF larvae. The fact that 86% of the farmers that do not yet use fly larvae in Benin are ready to do so opens perspectives for a larger dissemination of the technique (Pomalégni et al. 2016). The biggest issue for its widespread adoption is to find substrates that are free and not used for other purposes. Pomalégni et al. (2017) state that a series of suitable substrates should be proposed to allow villagers to use those that are available and free, or at least affordable, in their community.

Larger scale production units using the natural oviposition technique were developed in the 1990s in Benin (Nzamujo 1999) and Mali (Koné 1998) but until recently had not been properly evaluated. Koné et al. (2017) described a system set up in Mali as part of the PROteINSECT project and tested over a period of 2 years with different substrates. In brief, about 10 kg of dry substrates were placed in cement beds of about 1 m^2 under a roof, and moistened. For the first day, naturally occurring flies were allowed to oviposit on the substrate. At the end of the day, the substrates

Fig. 4 House fly larvae drying in the sun in Mali (Photo: M. Kenis)

were covered with ventilated plastic sheets and left for 2 days. On the fourth day, larvae were separated from the substrate using colanders that allowed the larvae to leave the substrate by themselves. The larvae were then left in containers for one night for purging of gut contents before being fed alive to animals, or either dried in the sun (Fig. 4) or in a solar drier. The rearing residues were sold as compost. Humidity in the substrates is essential for larval growth, but substrates that are too wet will also be detrimental for the growth and survival of larvae. Additionally, the depth of the substrate should not be more than 10 cm to avoid anoxia. The best substrates were chicken manure, alone or with ruminant blood, and sheep manure with ruminant blood. The system produced, on average, 124–144 g of fresh larvae per kg of dry substrate in 3 days, but with high variations between and within seasons. In the rainy season, a maximum of 427 g per kg of dry substrate were obtained. Besides the annual variations in yields, another issue with this system is that scaling up would require a large amount of ground surface. Nevertheless, experiments have shown that flies also oviposit (albeit at a lower rate) on substrates that are placed on shelves (Koné et al. 2017).

In such systems, rearing substrates have to be attractive for adults and suitable for larval development. Both animal and vegetal wastes can be used, but not all wastes are suitable. The protein content in the substrate undoubtedly plays an important role, as well as volatiles present in the substrates (Tang et al. 2016). Poultry and pig manure are suitable when used alone, but ruminant manures are productive only when animal proteins such as blood or animal offal are added (Mpoame et al. 2004; Koné et al. 2017; S. Nacambo unpublished data). Blood and animal offal can also improve yields on otherwise poor vegetal substrates such as decaying fruits and vegetables (Bouafou et al. 2006). However, some vegetal and agricultural wastes are suitable on their own, in particular those that contain a high amount of proteins such as brewery waste or legume wastes, but also fermented cereal brans (S. Nacambo, unpublished data). Aniebo et al. (2008) tested a mixture of cow and goat blood from a Nigerian abattoir with wheat bran, rice dust, and saw dust. Mixtures of 25 kg blood and 5 kg wheat bran produced an average of 7.16 kg of fresh HF larvae. It was calculated that the abattoir could potentially produce 2 tons of HF larvae per day. Abattoirs can also provide rumen contents, which is also a suitable substrate for HF production (Loa 2000), performing particularly well when mixed with cereal bran (S. Nacambo unpublished data).

2.8 Larvae Production Based on Adult Rearing

In most systems outside West Africa, HF larvae are produced by rearing adults in confinement to obtain eggs that are placed directly in suitable substrates. A detailed description of an adult HF rearing unit is provided by Čičková et al. (2012a), who developed two production units in Slovakia and Spain. The same teams carried out studies to improve the systems, e.g. on the oviposition substrates (Pastor et al. 2011) or on assessing differences in reproduction performances between geographic strains of the HF (Pastor et al. 2014). The HF production systems are also summarised and discussed by Čičková et al. (2015) and Pastor et al. (2015). In China, Zhejiang Province, a full scale housefly larvae bioconversion system for pig manure is described by Wang et al. (2013), including adult rearing procedures. Another, similar medium-scale system for chicken manure was developed as part of the PROteINSECT project by the Guangdong Entomological Institute (GEI) and briefly described in Charlton et al. (2015) and Cortes Ortiz et al. (2016). Basically, adult rearing is quite similar in all production systems. House flies are maintained in very high densities under controlled environments (temperature, humidity and light), in rearing rooms or cages of various sizes (e.g. from 25,000 flies in 0.7 m^3 in Čičková et al. (2012a) to 4.8 million flies in 48 m^3 in Wang et al. (2013)). Adults are fed with a mixture of carbohydrates (usually sugar), proteins (usually milk powder, sometimes yeast) and water. Eggs are laid on various oviposition devices filled with attractants, e.g. pig manure (Čičková et al. 2012a) or fermented wheat bran (Cortes Ortiz et al. 2016). Egg production may also depend on how the oviposition devices are placed. In Čičková et al. (2012a), cages in Spain, where the oviposition device was placed in the bottom of the cage, produced four times less than similar cages in Slovakia, where the oviposition sites were distributed over the cage.

The adult rearing technique is not easy to acquire for family farmers who cannot spend much time on this activity. Nevertheless, in the PROteINSECT project, small HF breeding systems were developed on farm in China and Ghana. In China, Huazhong Agricultural University (HZAU) established a rearing system on pig manure at a family farm in Hunan Province (Charlton et al. 2015) and this system

Fig. 5 Rearing of house fly adults for egg production in a farm in China (Photo: M. Roffeis)

Fig. 6 House fly production on pig manure in a farm in China (Photo: M. Roffeis)

has subsequently been adopted by many farmers in the region (Figs. 5 and 6). In Ghana, a similar system was established at the experimental farm of the NGO Fish for Africa (Charlton et al. 2015). Details on the study are provided in an unpublished MSc thesis (Maciel-Vergara 2014). In both systems, flies were reared in 1–2 m^3 gauze cages with about 20,000 flies per 1 m^3 (Fig. 5). Flies were fed with a mixture of sugar and dry milk, but, adding a hen's egg in the feed strongly enhanced oviposition in Ghana; to lower the costs, milk and hen's eggs were replaced by fresh mashed larvae in pilot trials (Maciel-Vergara 2014). The oviposition substrate consisted of fermented wheat bran in China whereas chicken manure, brewery waste or a mixture of both were used in Ghana. The oviposition substrate can be packed in bags made with pleated fabric to facilitate egg laying and egg collection. However, in the HZAU system in China, to prevent eggs from drying out, eggs were laid by females directly in the substrate, and freshly hatched larvae in the oviposition substrate, rather than eggs, were moved to the larval rearing substrate. The same strategy is proposed by Wang et al. (2013). The main difference between these small-scale systems and large production units is that the environmental conditions in which the rearing cages were maintained were not controlled. The cages were set up in open rooms without temperature or humidity control and under natural light. As a result, egg production was less consistent and, on an annual basis, much lower than those obtained under fully controlled conditions. In China, rearing was stopped in winter between November and March and was less efficient when temperatures were too high in summer. In Ghana, fly activity and egg production was also very dependent on season and daily climatic conditions.

Rearing adult flies for egg production also implies that healthy and strong adults have to be produced. Adult fecundity and longevity depends on the conditions experienced in the larval stages and, so, rearing the larvae in the best conditions will ensure that females are capable of producing large amounts of eggs (Pastor et al. 2015). Hence, it is important to keep the larvae for adult production in a nutritious substrate until pupation. This may imply a totally different larval production chain. For example, in the GEI system in China, while larvae for poultry consumption were produced on chicken manure, those intended for adult production were reared on fermented wheat bran (Cortes Ortiz et al. 2016).

The systems based on adult rearing use basically the same substrates as those used in natural oviposition because, in most cases, a substrate that is suitable for larval development will also attract female flies for oviposition. About one gram of HF eggs per 10 kg of wet pig manure is recommended in the HZAU family farm system, to produce about 1 kg of fresh larvae (Charlton et al. 2015; F. Zhu unpublished data) (Fig. 6). The GEI system recommends 1 g of eggs per 3 kg of wet chicken manure for a fresh yield of 2–3 kg, depending on the water content of wet chicken manure. In Ghana, 3 g of eggs per 9 kg of wet substrate (mixtures of chicken manure, brewery waste and fish feed waste) produced an optimal fresh larval yield of 670 g (Maciel-Vergara 2014). As for the natural oviposition system, the humidity of the substrate during larval development is critical. The substrate should remain humid during larval growth, but stagnant water should be avoided. The depth of the substrate should be around 7–10 cm to avoid anoxia (Cortes Ortiz et al. 2016; Authors, unpublished data).

Ideally, substrates based on manure should be pre-treated by fermentation to kill heat-sensitive pathogens (Cortes Ortiz et al. 2016), but this is rarely possible in small-scale farm systems.

2.9 Extraction of Larvae and Pupae

In small systems where the larvae are fed live to poultry or fish, the separation of larvae from rearing substrates can be easily achieved using various sieving systems (Koné et al. 2017; Pomalégni et al. 2017). When placed on a sieve in the sunlight, larvae tend to leave the substrate and crawl through the sieve. However, the type of sieve needed depends on the substrate used. In the HZAU system that uses pig manure, mature larvae are simply collected with a broom and a shovel before being fed to chickens (Charlton et al. 2015). A similar method was used by Wang et al. (2013) who, in addition, used a sieve to remove residual solids. For larger scale productions, automatized systems have been developed, either with sieves or using totally different systems. In the GEI system, larvae are extracted from the chicken manure by lowering the oxygen concentration, which forces the larvae to leave the rearing containers (Cortes Ortiz et al. 2016). Čičková et al. (2012b) developed a behavioural method to extract larvae from processed pig manure. In a dark room, a cover was placed over larval rearing trays that were then placed in larger collection trays. After 24 h of separation, 74% of the larvae had egressed from the manure into the collection tray, probably because of the lack of oxygen and accumulation of noxious metabolic products. An advantage of the system compared to sieves was that egressed larvae were free of any manure particles and purged of gut contents. In general, larvae should be purged for at least 12 h before being given to poultry, or dried to minimise the amount of substrate that is eaten by the animals or to maximise the purity of dry larvae. Another extraction system sometimes cited in experiments is flotation (Akpodiete et al. 1998; Adenji 2007). However, this was never applied at larger scale, probably because it is more time consuming and dependent upon the availability of large volumes of water.

As for BSF, the presence of parasitoids may hamper HF production, mainly at the pupal stage. Several hymenopterous parasitoids are known from HF (e.g. Legner and Greathead 1969; Skovgård and Jespersen 1999). Biological parameters related to these parasitoids, such as development time, parasitism rates and superparasitism have shown a positive correlation to temperatures up to 35 °C (Mann et al. 1990) suggesting that, in tropical climates, parasitoids have the potential to cause concern in HF production systems.

2.10 Killing and Drying

When larvae are not consumed directly after extraction or purging, they have to be killed and dried for preservation. Dried maggots can be stored in a sealed container for several months or even years (Koné et al. 2017). Various types of ovens and other drying methods can be used but the easiest ones, such as gas or electric ovens or microwaves (Cortes Ortiz et al. 2016), are usually costly and energy-demanding. In warm climates, HF larvae that are smaller than BSF can be dried in the direct sun on a metal sheet, within a day (Koné et al. 2017). In the rainy season, however, the larvae should first be killed and dried a few minutes on a cooker (Koné et al. 2017). For a medium-scale larvae production unit in the tropics, the best method is to use a solar dryer, but models need to be specifically designed for this purpose (Maciel-Vergara 2014).

3 Discussion and Recommendations

Both HF and BSF have been used and promoted as alternative animal feed ingredients. Industrial systems now seem to focus largely on BSF, except in China, where several HF production systems have recently been established. Small-scale production systems have been developed for the two species, and both have advantages and disadvantages. A comparison of the two species is provided in Table 1. The choice for one or another species should be made according to the location, substrates availability, priorities, etc. The comparison in Table 1 is largely made from the experience gathered in PROteINSECT where several systems based on the two fly species have been tested in rural environments in West Africa and China (Maciel-Vergara 2014; Devic et al. 2014; Charlton et al. 2015; Koné et al. 2017).

It must be noted that, in developed countries, a true economic profitability (as compared to the cost of using standard animal protein sources) may be reached only through high mechanisation and automatization because of high wage costs. Small-scale systems can however be considered by specific categories of consumers, such as hobby gardeners or hobby pet breeders. In contrast, in countries where wages in the agricultural sector are low, such small-scale systems may provide an alternative to regular protein sources that are not always available and are often of low quality. For smallholder farmers, they may also be a unique source of protein for malnourished poultry and fish (Pomalégni et al. 2016).

Individual farmers that cannot devote a large amount of time to larval production should consider natural oviposition systems. BSF production may cause fewer nuisances but is more complicated and longer to implement than the HF natural oviposition system, which is already used by a significant proportion of farmers in West Africa (Pomalégni et al. 2017).

Larger farms or small enterprises that can devote staff time to larval production may consider systems with adult rearing, either with BSF or with HF. HF adults are slightly easier to rear and offer other advantages such as smaller larvae that can be easily dried, directly used in animal feed, and contain higher amounts of proteins. BSF also offer advantages, in particular very high yields (when a good substrate is used) and a wider variety of suitable substrates. Moreover, BSF has a better reputation than HF because adults are not associated with human and animal diseases. However, when flies are kept their whole life in cages, this particular risk is minimal. Natural oviposition is also suitable for larger-scale production, as described in Koné et al. (2017), but requires a relatively large ground surface area for commercial production. Furthermore, yields may vary strongly with seasons. Casual observations have shown that HF production does not increase the number of adult flies around the farm homestead, but this needs to be studied further.

Table 1 Comparison between house fly and black soldier fly of parameters that may affect small-scale production systems

Parameter	House fly	Black soldier fly
Production cycle	☺ Very short; in the tropics only 3–6 days are required between egg laying and harvesting of larvae.	😐 Longer; even in tropical climates at least 13–15 days are needed between oviposition and harvesting of larvae. If pre-pupae are collected through self-migration, a few more days are required.
Climatic suitability	☺ Very widespread and ubiquitous. HF can be reared in many climates, although cold temperatures will result in slow development. Successful HF production through larval production has been obtained in the warmest and driest months in the Sahel.	☹ Narrower climatic suitability; BSF naturally occur only in the tropics and warm temperate climates and does not like very dry climates.
Substrate suitability	😐 Many substrates can be used but vegetal wastes, e.g. from market, are less suitable for HF than for BSF, except when they contain a high amount of proteins (e.g. legumes).	☺ Even more substrates can be used than for HF. In particular, vegetal wastes, e.g. from market, are usually better accepted than in HF while some animal wastes such as animal offal tend to be less suitable.
Natural oviposition system	☺ Very suitable and easy to implement in the tropics, especially by small farmers.	😐 Less suitable. Methods exist but they need more sophisticated equipment, are less reliable and practical and, because BSF are less abundant naturally, populations often need to be increased locally.
Adult rearing and egg production	😐 Colony maintenance on a regular basis is easy but can be time consuming. High oviposition rates imply adult food that can be expensive (e.g. milk powder, sugar, egg).	😐 Colony maintenance requires less time but more expertise. Adults do not feed, so no investment is needed in feed but in oviposition substrates.
Expertise required	☺ Little expertise needed for natural oviposition systems. More for a full system with adult rearing, but HF eggs are easier to produce than BSF eggs.	☹ The most suitable system, with egg production, requires expertise, especially for the adult rearing stage. Thus, a BSF production is better conceived as a small enterprise with full time personnel. Natural oviposition systems exist, but see above.
Safety	☹ Adult HF can be vectors of human and animal diseases. This should not be a concern for HF reared in captivity, but natural oviposition systems may potentially increase the prevalence of these diseases (research on-going). These should be set up at a certain distance from buildings. Feed safety issues are related to the substrate used and are thus independent of the fly species.	☺ Adult BSF do not feed and, thus, are not vectors of human and animal diseases. Besides, a system based on caged BSF adults will cause fewer nuisances to the neighbourhood than a HF natural oviposition system. Feed safety issues are related to the substrate used and are thus independent of the fly species.

(continued)

Table 1 (continued)

Parameter	House fly	Black soldier fly
Larvae extraction	😐 Various methods exist, mainly using sieving systems, but obtaining larvae with low levels of impurities can be time consuming.	😐 Pre-pupae can be easily self-harvested. If larvae are preferred for their higher digestibility, extraction is about as easy as HF.
Drying	☺ Larvae are smaller and can more easily be dried in the sun or a solar dryer.	☹ Larvae are much bigger and contain much water. Thus, they cannot easily be dried in the sun or in a solar dryer.
Yields	😐 The maximum yields per substrate dry weight are lower than for BSF.	☺ The maximum yields per substrate dry weight can be higher than for HF.
Quality as feed	☺ HF larvae have higher crude protein content (average of studies 50.4%, Makkar et al. 2014). Larvae are small and can be fed live to all animals. Dried larvae can be added to animal feed.	😐 BSF larvae have a lower crude protein content (average of studies 42.1%, Makkar et al. 2014 – But see Marono et al. 2015), and pre-pupae are less digestible. Larvae and pre-pupae may not be suitable for young chicks and fish. Dried larvae should be ground before being added to animal feed.

No matter the fly or system used, a free or cheap, abundantly available substrate is essential for the success of a fly larval production initiative, even at small-scale. To this effect, it is important to keep the transportation distances as short as possible. Ideally, a production unit should be placed in the neighbourhood of a substrate providing system, such as an agro-industrial factory, a fruit and vegetable market, a large farm or animal husbandry, an abattoir, etc. To sustain profitability, especially in small fly larval production systems, attention should also be given to the marketing opportunities of fly rearing residues, which make excellent soil conditioners. In the system developed by Kone et al. (2017) in Mali, the rearing residues were sold at the same or higher price, per dry weight, as compared to the manures used as rearing substrates.

To date, very few studies on the economic profitability of fly larval production systems have been published. In all developments of fly larvae production systems, the impacts on household nutrition, income and livelihoods should be assessed relative to the traditional systems. Similarly, the environmental sustainability of the systems should be better assessed and compared with conventional feed systems, e.g. through life cycle assessments (Halloran et al. 2016). The potential impact of fly larval production on waste management systems should also be included in the assessments, as well as the value of residues from on-farm rearing systems.

The use of fly larvae in animal feed is a new science and, thus, further research is essential to enable technical optimisation of production systems, harvesting and drying methods, for the different types of production systems. Further studies are needed on the safety of insect rearing systems and insect-based feed for animal and human health, considering that the main risks come from the substrates and that each type of substrate may represent different risks (Nkegbe et al. 2018). Finally, although fly larvae represent a natural feed for poultry in rural areas, the acceptability of eating animals fed with insects may have to be improved, in particular among urban consumers. More generally, ways to improve the reception and implementation of the techniques need to be evaluated e.g. through socio-anthropological analyses.

Acknowledgements This review was made in the framework of the project PROteINSECT of the European Union's Seventh Framework Programme for research, technological development and demonstration (grant agreement no. 312084) and the project IFWA – Insects as Feed in West Africa, funded by the Swiss Programme for Research on Global Issues for Development (R4D).

References

Adenji AA (2007) Effect of replacing groundnut cake with maggot meal in the diet of broilers. Int J Poultry Sci 6:822–825

Akpodiete OJ, Ologhobo AD, Onwade AA (1998) Maggot meal as a substitute for fish meal in laying chicken diet. J Agric Sci 31:137–142

Aniebo AO, Wekhe SN, Erondu ES, Owen OJ, Ngodigha EN, Isirimah NO (2008) Sustainable commercial maggot production (maggotry) for animal and aqua feeds in rivers state, South Nigeria. Int J Biotechnol Biochemist 4:197–205

Axtell RC, Arends JJ (1990) Ecology and management of arthropod pest of poultry. Annu Rev Entomol 35:101–126

Barry TMA (2004) Evaluation of the economic, social, and biological feasibility of bioconverting food wastes with the black soldier fly (*Hermetia illucens*). PhD Thesis, University of North Texas

Bouafou KGM, Kouame KG, Amoikon EK, Offoumou AM (2006) Potentiels pour la production d'asticots sur des sous- produits en Côte d'Ivoire. Tropicultura 24:157–161

Bradley SW, Booth DC, Sheppard DC (1984) Parasitism of the black soldier fly by *Trichopria* sp. (Hymenoptera: Diapriidae) in poultry houses. Environ Entomol 13:451–454

Bullock N, Chapin E, Evans A, Elder B, Givens M, Jeffay N, Pierce B, Robinson W (2013) The black soldier fly how-to-guide. UNC Institute for the environment. ENST 698-Environmental Capstone

Caruso D, Devic E, Subamia IW, Talamond P, Baras E (2014) Technical handbook of domestication and production of Diptera Black Soldier Fly (BSF) *Hermetia illucens*, Stratiomyidae. IRD Edition, Marseille

Charlton AJ, Dickinson M, Wakefield ME, Fitches E, Kenis M, Han R, Zhu F, Kone N, Grant M, Devic E, Bruggeman G, Prior R, Smith R (2015) Exploring the chemical safety of fly larvae as a source of protein for animal feed. J Insects Food Feed 1:7–16

Čičková H, Pastor B, Kozánek M, Martínez-Sánchez A, Rojo S, Takác P (2012a) Biodegradation of pig manure by the housefly, *Musca domestica*: a viable ecological strategy for pig manure management. PLoS One 7:e32798

Čičková H, Kozánek M, Morávek I, Takác P (2012b) A behavioral method for separation of house fly (Diptera: Muscidae) larvae from processed pig manure. J Econ Entomol 105:62–66

Čičková H, Kozánek M, Takác P (2013) Improvements of survival of the house fly (*Musca domestica* L.) larvae under mass rearing conditions. Bull Entomol Res 103:119–125

Čičková H, Newton GL, Lacy RC, Kozánek M (2015) The use of fly larvae for organic waste treatment. Waste Manag 35:68–80

Cortes Ortiz JA, Ruiz AT, Morales-Ramos JA, Thomas M, Rojas MG, Tomberlin JK, Yi L, Han R, Giroud L, Jullien RL (2016) Chapter 6. Insect mass production technologies in Dossey AT, Morales-Ramos JA, Guadalupe Rojas M (eds) Insects as sustainable food ingredients. Academic, San Diego, p 153–201

Devic E, Anankware JP, Murray F, Little DC (2014) Breeding flies in Ghana: implications of scaling up from pilot trials to commercial production scale. In: Abstracts of the conference on insects to feed the world, Ede, 14–17 May 2014

Devic E, Maquart P-O (2015) *Dirhinus giffardii* (Hymenoptera: Chalcididae), parasitoid affecting Black Soldier Fly production systems in West Africa. Entomologia 3:284

Diener S, Studt Solano NM, Roa Gutiérrez F, Zurbrugg C, Tockner K (2011a) Biological treatment of municipal organic waste using black soldier fly larvae. Waste Biomass Valorization 2:357–363

Diener S, Zurbrügg C, Gutiérrez FR, Nguyen DH, Morel A, Koottatep T, Tockner K (2011b) Black soldier fly larvae for organic waste treatment— prospects and constraints. In: Proceedings of the WasteSafe — 2nd international conference on solid waste management in the developing countries, Khulna, Bangladesh, 13–15 Feb 2011

Diener S, Lalander C, Zurbrugg C, Vinnerås B (2015) Opportunities and constraints for medium scale organic waste treatment with fly larvae composting. In: Proceedings of the 15th International waste management and landfill symposium, Cagliari, Sardinia, 5–9 Oct 2015

Drew DJW, Pieterse E (2015) Markets, money and maggots. J Insects Food Feed 1:227–231

Gobbi FP (2012) Biología reproductiva y caracterización morfológica de los estadios larvarios de *Hermetia illucens* (L., 1758) (Diptera: Stratiomyidae). Bases para su producción masiva en Europa. PhD Thesis, Universidad de Alicante

Gobbi FP, Martínez-Sánchez A, Rojo S (2013) The effects of larval diet on adult life-history traits of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). Eur J Entomol 110:461–468

Greenberg B (1973) Flies and disease, Biology and disease transmission, vol 2. Princeton Univ. Press, New Jersey

Halloran A, Roos N, Eilenberg J, Cerutti A, Bruun S (2016) Life cycle assessment of edible insects for food protein: a review. Agron Sustain Dev 36:57

Hem S, Toure S, Sagbla C, Legendre M (2008) Bioconversion of palm kernel meal for aquaculture: experiences from the forest region (Republic of Guinea). Afr J Biotechnol 7:1192–1198

Hewitt CG (1914) The house-fly, its structure, habits, development, relation to disease control. University Press, Cambridge England

Holmes LA, Vanlaerhoven SL, Tomberlin JK (2012) Relative humidity effects on the life history of *Hermetia illucens* (Diptera: Stratiomyidae). Environ Entomol 41:971–978

Holmes LA, Vanlaerhoven SL, Tomberlin JK (2013) Substrate effects on pupation and adult emergence of *Hermetia illucens* (Diptera: Stratiomyidae). Environ Entomol 42:370–374

Holmes LA, Van Laerhoven SL, Tomberlin JK (2016) Lower temperature threshold of black soldier fly (Diptera: Stratiomyidae) development. J Insects Food Feed 2:255–262

Kalová M, Borkovcová M (2013) Voracious larvae *Hermetia illucens* and treatment of selected types of biodegradable waste. Acta Universitatis Agriculturae Silviculturae Mendelianae Brunensis 61:77–83

Kenis M, Koné N, Chrysostome CAAM, Devic E, Koko GKD, Clottey VA, Nacambo S, Mensah GA (2014) Insects used for animal feed in West Africa. Entomologia 2:107–114

Koné N'G (1998) Mise au point d'un procédé industriel de production de larves de mouche (asticots). Document de Brevet N° 10808 de l'Organisation Africaine de la Propriété Intellectuelle (OAPI) du 30 juin 1999

Koné N'G, Sylla M, Nacambo S, Kenis M (2017) Production of house fly larvae for animal feed through natural oviposition. J Insects Food Feed 3:187–192

Legner EF, Greathead DJ (1969) Parasitism of pupae in east African populations of *Musca domestica* and *Stomoxys calcitrans*. Ann Entomol Soc Am 62:128–133

Loa C (2000) Production et utilisation contrôlées d'asticots. Tropicultura 18:215–219

Maciel-Vergara G (2014) Improvement of a house fly maggot production system for animal feed in Ghana. MSc thesis, University of Catania, Italy, and University of Copenhagen, Denmark

Makkar HPS, Tran G, Heuzé AP (2014) State-of-the-art on use of insects as animal feed. Anim Feed Sci Tech 197:1–33

Mann JA, Axtell RC, Stinner RE (1990) Temperature-dependent development and parasitism rates of four species of *Pteromalidae* (Hymenoptera) parasitoids of house fly (*Musca domestica*) pupae. Med Vet Entomol 4:245–253

Marono S, Piccolo G, Loponte R, Di Meo C, Attia YA, Nizza A, Bovera F (2015) In vitro crude protein digestibility of *Tenebrio Molitor* and *Hermetia Illucens* insect meals and its correlation with chemical composition traits. Ital J Anim Sci 14(3):3889

Mpoame M, Teguia A, Nguemfo EL (2004) Essai comparé de production d'asticots dans les fientes de poule et dans la bouse de vache. Tropicultura 22:84–87

Newton GL, Watson DW, Dove R, Sheppard C, Burtle G (2005) Using the black soldier fly, *Hermetia illucens*, as a value added tool for the management of swine manure. Report for Mike Williams, Director of the animal and poultry waste Management Center, North Carolina State University, Raleigh

Nguyen TTX, Tomberlin JK, Vanlaerhoven S (2013) Influence of resources on *Hermetia illucens* (Diptera: Stratiomyidae) larval development. J Med Entomol 50:898–906

Nyakeri EM, Ogola HJ, Ayieko MA, Amimo FA (2017) An open system for farming black soldier fly larvae as source of proteins for smallscale poultry and fish production. J Insects Food Feed 3:51–56

Nkegbe E, Adu-Aboagye G, Nacambo S, Kenis M, Wallace P (2018) Potential health and safety issues in the small-scale production of fly larvae for animal feed, with particular focus on Africa – a review. Ghana J Agric Sci. (In Press)

Nzamujo OP (1999) Technique for maggot production. The Songhai experience. Unpublished Report

Park HH (2016) Black soldier fly larvae manual. Student Showcase 14. http://scholarworks.umass.edu/sustainableumass_studentshowcase/14

Pastor B, Čičková H, Kozánek M, Martínez-Sánchez A, Takác P, Rojo S (2011) Effect of the size of the pupae, adult diet, oviposition substrate and adult population density on egg production in *Musca domestica* (Diptera: Muscidae). Eur J Entomol 108:587–596

Pastor B, Martínez-Sánchez A, Ståhls GA, Rojo S (2014) Introducing improvements in the mass rearing of the housefly: biological, morphometric and genetic characterization of laboratory strains. Bull Entomol Res 104:486–493

Pastor B, Velasquez Y, Gobbi P, Rojo S (2015) Conversion of organic wastes into fly larval biomass: bottlenecks and challenges. J Insects Food Feed 1:179–193

Pomalégni SCB, Gbemavo DSJC, Kpadé CP, Babatoundé S, Chrysostome CAAM, Koudandé OD, Kenis M, Glèlè Kakaï RL, Mensah GA (2016) Perceptions et facteurs déterminant l'utilisation des asticots dans l'alimentation des poulets locaux (*Gallus gallus*) au Bénin. J Appl Biosci 98:9330–9343

Pomalégni SCB, Gbemavo DSJC, Kpadé CP, Kenis M, Mensah GA (2017) Traditionnal use of fly larvae by small poultry farmers in Benin. J Insects Food Feed 3:187–192

Rachmawati BD, Hidayat P, Hem S, Fahmi MR (2010) Development and nutrional content of *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) larvae on oil palm kernel. J Entomol Indonesia 7:28–41. (in Indonesian)

Rana KS, Salam MA, Hashem S, Islam MA (2015) Development of black soldier fly larvae production technique as an alternate fish feed. Int J Res Fish Aquac 5:41–47

Roffeis M, Muys B, Almeida J, Mathijs E, Achten WMJ, Pastor B, Velásquez Y, Martínez-Sánchez AI, Rojo S (2015) Pig manure treatment with house fly (*Musca domestica*) rearing – an environmental life cycle assessment. J Insects Food Feed 1:195–214

Sheppard DC, Newton LG, Thompson SA, Savage S (1994) A value added manure management system using the black soldier fly. Bioresour Technol 50:275–279

Sheppard DC, Tomberlin JK, Joyce JA, Kiser BC, Sumner SM (2002) Rearing methods for the black soldier fly (Diptera: Stratiomyidae). J Med Entomol 39:695–698

Skovgård H, Jespersen JB (1999) Activity and relative abundance of hymenopterous parasitoids that attack puparia of *Musca domestica* and *Stomoxys calcitrans* (Diptera: Muscidae) on confined pig and cattle farms in Denmark. Bull Entomol Res 89:263–269

Tang R, Zhang F, Koné NG, Chen J-H, Zhu F, Han R-C, Lei C-L, Kenis M, Huang L-Q, Wang C-Z (2016) Identification and testing of oviposition attractant chemical compounds for *Musca domestica*. Sci Rep 6:33017

Tomberlin JK, Sheppard DC (2001) Lekking behavior of the black soldier fly (Diptera: Stratiomyidae). Fla Entomol 84:729–730

Tomberlin JK, Sheppard DC (2002) Factors influencing mating and oviposition of black soldier flies (Diptera: Stratiomyidae) in a colony. J Entomo Sci 37:345–352

Tomberlin JK, Adler PH, Myers HM (2009) Development of the black soldier fly (Diptera: Stratiomyidae) in relation to temperature. Environ Entomol 38:930–934

Van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

Van Huis A, Van Itterbeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects future prospects for food and feed security. FAO forestry paper 171, Food and Agriculture Organization, Rome

Wang H, Zhang Z, Czapar G, Winkler MKH, Zheng J (2013) A full-scale house fly (Diptera: Muscidae) larvae bioconversion system for value-added swine manure reduction. Waste Manag Res 31:223

West LS (1951) The housefly, its natural history, medical importance, and control. Comstock Publ. Co, Ithaca

Yehuda B, Marchaim U, Glatman L, Drabkin V, Chizov-Ginzburg A, Mumcuoglu KY, Gelman A (2011) Bioconversion of poultry and fish waste by *Lucilia Sericata* and *Sarcophaga carnaria* larvae. Asian J Water Environ Pollut 8:69–75

Zhang J, Huang L, He J, Tomberlin JK, Li J, Lei C, Sun M, Liu Z, Yu Z (2010) An artificial light source influences mating and oviposition of black soldier flies, *Hermetia illucens*. J Insect Sci 10:202

Insects as Raw Materials in Compound Feed for Aquaculture

Erik-Jan Lock, Irene Biancarosa, and Laura Gasco

Abstract Already in the early phases of the development of a European insect industry, aquafeed was suggested as one of the first animal feeds where insect products could be implemented. Since then, substantial progress has been made by the research community and feed producers to test various types of insect species and insect products as part of a complete feed for aquaculture. These (mostly extruded) feeds are typically high in energy and protein content which demands specifics characteristics of the raw materials. The role insects, high in protein and lipids, can play in these diets will be reviewed and discussed in this chapter. We will shortly touch on topics like the effect of insect feeding substrate, insect processing and chitin that all can have an effect on insect meal. Finally, feed safety considerations related to the use of insects in aquafeeds will be reviewed and discussed.

1 Introduction

Compound feed contains macro- and micronutrients in levels that fulfil the animal's requirements for healthy growth under intensive rearing conditions. Compound feed normally contains animal- and/or plant-based feed materials to which micronutrients (vitamins, minerals) are added. The most used feed ingredients are fishmeal, krill meal, soy protein concentrate, corn gluten meal, wheat gluten, fish oil and rapeseed oil amongst others. Animal by-products, like feather meal or blood meal are also used (Except for Norway) and novel feed materials are investigated like, seaweed, microalgae, bacterial protein meal, and insects. Diets for carnivorous fish

E.-J. Lock (✉) · I. Biancarosa
Institute of Marine Research (IMR), Bergen, Norway
e-mail: elo@nifes.no; ibi@nifes.no

L. Gasco
Università degli studi di Torino, Torino, Italy
e-mail: laura.gasco@unito.it

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_16

like rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*) are high-energy diets, characterized by high contents of lipids and protein, and low levels of carbohydrates. Animal-based feed ingredients, like insects, fit these constraints much better then vegetable-based feed ingredients. The nutrient content of various insect species has been widely studied and is reviewed in several articles (Rumpold and Schluter 2013; Barroso et al. 2014; Makkar et al. 2014; Sanchez-Muros et al. 2014; Henry et al. 2015). Fish prey on insects in their natural environment and to include insects in a compound feed is self-evident from a natural perspective. However, also from a nutritional perspective insects can be a valuable feed ingredient and will be discussed in the following sections.

2 Inclusion of Insect Raw Materials in Compound Feed for Fish

A large number of insect species can potentially be considered for their inclusion in fish diets. However, the interest towards the use of insect ingredients in aquafeeds focusses mainly around a few insect species that can be produced on a large scale. The investigations conducted so far mainly concern the use of larvae meals obtained from *Tenebrio molitor* (TM), *Hermetia illucens* (HI) and *Musca domestica* (MD). While a relatively large number of research articles exists on insect meals in warm water fish species (Henry et al. 2015), very few studies have investigated the effects of insect meals (IM) in salmonids (Table 1) or marine species (Table 2).

The results of the existing studies differ, depending on fish species considered, IM inclusion levels and types, and feed formulation. Including a new ingredient means replacement of another ingredient in the diet. In most studies, fishmeal (FM) is replaced; however other studies replaced plant-based ingredients, resulting in not directly comparable results. Finally, a replacement of FM by IM is often expressed as % replacement of FM. Since the amount of FM varies between studies, direct comparisons of % replacement is not always possible.

2.1 Growth Performance and Feed Utilisation

The use of IM in salmonid diets was already investigated in the 1980s (Akiyama et al. 1984) with the aim of stimulating feed ingestion or palatability. A part of the FM was substituted by low levels (5%) of silkworm pupae or earthworm powder in swim-up fry diets. The use of earthworm powder resulted in a weight gain (WG) and feed efficiency improvement of 30% and 39% respectively. Silkworm meal slightly improved feed efficiency while neither source increased the palatability of the fish diet, measured as daily food consumption.

Table 1 Growth performances of salmonids fed insect meals diets compared to FM (or other protein sources) control diet

Species	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FC	FR	FE	PER	FCR	SGR	Reference
Chum salmon (*Oncorhynchus keta*)	Control	0.2	–	–	69.2	–	45.6	–	–	–	–	b	a	–	c	–	–	–	Akiyama et al.(1984)
	SW		–	Commercial products	64.8		49.5	6.36	5	–	–	b	b	–	b	–	–	–	
	EW				64.4		46.4	6.94	5	–	–	a	c	–	a	–	–	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	22.5	–	–	36.0	CGM (8) SBM (16)	39.1	–	–	a	–	a	nd	–	–	–	a	–	St-Hilaire et al. (2007)
	HI		Pig manure	–	27.0		37.4	25.0	14.9	ab	–	ab	nd	–	–	–	a	–	
	HI		Pig manure		18.0		37.5	50.0	29.8	b	–	b	nd	–	–	–	b	–	
	MD		Cow manure		27.0		41.0	25.0	9.2	b	–	b	nd	–	–		a	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	146.0	–	–	29.1	CGM (7) SBM (16) WGM (7.8)	46.0	0	0	–	a	–	nd	–	–	–	nd	–	Sealey et al. (2011)
	NHI		Cow manure	Freeze grinded + dried full fat prepupae	21.8		48.5	25.0	16.4	–	b	–	nd	–	–	–	nd	–	
	NHI				14.5		50.4	50.0	32.8	–	b	–	nd	–	–	–	nd	–	
	EHI		Cow manure + fish offal		21.8		51.2	25.0	18.1	–	ab	–	nd	–	–	–	nd	–	
	EHI				14.5		52.5	50.0	36.2	–	ab	–	nd	–	–	–	nd	–	
Rainbow trout (*Oncorhynchus mykiss*)	Control	115.6	–		75.0	–	45.2	0	0	nd		nd	–	a	–	b	a	b	Belforti et al. (2015)
	TM		Wheat bran	Oven dried (full fat)	49.0	–	44.6	34.7	25.0	nd		nd	–	ab	–	a	b	a	
					25.0	CGM (5)	44.8	66.7	50.0	nd		nd	–	b	–	a	b	a	

(continued)

Table 1 (continued)

Species	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FC	FR	FE	PER	FCR	SGR	Reference
Atlantic salmon (*Salmo salar*)	Control	247	Food organic waste streams		20.0	WGM (20) SPC (20)		0	0				–	–	–	–		–	Lock et al. (2016)
	HIA			Dried partially defatted larvae meals	15.0	WGM (20) SPC (19.7)		25.0	5.0				–	–	–	–		–	
					10.0	WGM (19.4) SPC (20.2)		50.0	10.0				–	–	–	–		–	
					0	WGM (19.1) SPC (22.3)		100.0	25.0	*			–	–	–	–	*	–	
	HIB				15.0	WGM (20) SPC (20.8)		25.0	5.0	*			–	–	–	–	*	–	
					0	WGM (17.5) SPC (21.9)		100.0	25.0	*	*		–	–	–	–	*	–	

Rainbow trout (*Oncorhynchus mykiss*)	Control	179.0	Plant substrate	Dried partially defatted larvae meal	60.0	WM (4)	45.2	0	0	nd	–	nd	–	nd	–	nd	nd	nd	Renna et al. (2017)
	HI				45.0		44.9	25.0	20.0	nd	–	nd	–	nd	–	nd	nd	nd	
					30.0		45.0	50.0	40.0	nd	–	nd	–	nd	–	nd	nd	nd	

FM Fishmeal, *SW* Silkworm, *EW* Earthworm, *HI* Hermetia illucens, *MD* Musca domenstica, *NHI Hermetia illucens* prepupae reared in normal cow manure, *EHI Hermetia illucens* prepupae reared in cow manure enriched with fish offal, *HIA Hermetia illucens* larvae meal containing 25.5 lipid, *HIB Hermetia illucens* larvae meal containing 17% lipid, *TM Tenebrio molitor, SBM* soybean meal, *CGM* Corn gluten meal, *WGM* Wheat gluten meal, *SPC* Soy protein concentrate, *CP* crude protein, *IBW* Initial body weight (g), *FBW* Final body weight (g), *WG* Weight gain (g): FBW – IBW, WG (%) = FBW – IBW/ IBW * 100; *FC* Feed consumption = grams feed consumed per 100 g body weight per day, *FR* feeding rate (%/day) = [total feed supplied (g DM) * 100%/number of feeding days)]/e(lnIBW + lnFBW)*0.5], *FE* Feed efficiency = WG/ dry food intake, *PER* Protein efficiency ratio = wet weight gain (g)/total protein intake (g), *FCR* Feed conversion ratio = Ingested feed (g)/wet weight gain (g), *SGR* Specific growth rate (%/ day) = {(ln final fish weight ± ln initial fish weight)/days}* 100. Columns with different superscripts (a, b) are significantly different at $P < 0.05$; * Significantly different from control diet ($P < 0.05$) - no information; *nd* no differences

Table 2 Growth performances of marine species fed insect meals diets compared to FM (or other protein sources) control diet

Species	Insect meal	IBW (g)	Rearing substrate	Insect processing	FM in diet (%)	Other protein source (%)	% CP in diet (%DM)	FM (or other protein source) substitution) (%)	% Insect meal dietary inclusion	FBW	WG%	WG	FIFC	FR	PER	FCR	SGR	Reference
Turbot (*Psetta maxima*)	Control	54.9	–	–	68.7	WP (2) BM (5)	54.8	0	0	nd	–	–	a	–	–	a	a	Kroeckel et al. (2012)
	HI		Green house waste	Frozen, partially defatted, oven dried prepupae	55.0		54.9	20.0	16.5	nd	–	–	a	–	–	a	b	
					42.2		53.7	40.0	33.2	nd	–	–	a	–	–	ab	b	
					30.5		53.9	55.0	48.6	nd	–	–	b	–	–	b	c	
					18.0		53.3	74.0	64.0	nd	–	–	b	–	–	c	d	
					8.0		52.7	88.0	75.6	nd	–	–	c	–	–	d	e	
European sea bass (*Dicentrarchus labrax*)	Control	5.2	–		70.0	WGM (5.0)	59.6	0	0	a	–	a	–	a	nd	nd	a	Gasco et al. (2016)
	TM		Wheat bran	Oven dried (full fat)	45.0	WGM (7.5) CGM (2.8)	59.0	35.7	25.0	ab	–	ab	–	ab	nd	nd	ab	
					20.0	WGM (15)	59.5	71.4	50.0	b	–	b	–	b	nd	nd	b	
Gilthead sea bream (*Sparus aurata*)	Control	105.0	–		50.0	15.0 (CGM)	46.0	0	0	b	b	–	–	–	b	a	b	Piccolo et al. (2017)
	TM		Wheat bran	Oven dried (full fat)	33.3	12.5 (CGM)	45.7	33.4	25.0	a	a	–	–	–	a	b	a	
					13.0	13.0 (CGM)	45.2	74.0	50.0	b	b	–	–	–	b	a	b	

FM Fishmeal, *HI Hermetia illucens, TM Tenebrio molitor, WP* Wheat protein, *BM* Blood meal, *CGM* Corn gluten meal, *WGM* Wheat gluten meal, *CP* crude protein, *IBW* initial body weight (g), *FBW* Final body weight (g), *WG* Weight gain (g): FBW – IBW; WG (%) = FBW – IBW/ IBW * 100; *FC* Feed consumption = grams feed consumed per 100 g body weight per day, *FR* feeding rate, (%/day) = [total feed supplied (g DM) * 100%/number of feeding days)]/e(lnIBW + lnFBW)*0.5]; *PER* Protein efficiency ratio = wet weight gain (g)/total protein intake (g), *FCR* Feed conversion ratio = Ingested feed (g)/wet weight gain (g)/, *SGR* Specific growth rate (%/day) = {(ln final fish weight ± ln initial fish weight)/days}* 100. Columns with different superscripts (a, b, c) are significantly different at P < 0.05. - no information; *nd* no differences

St-Hilaire et al. (2007) investigated the use of a full fat pre-pupae HI meal used in partial substitution of FM and fish oil (FO) in the diet of rainbow trout. HI meal was included at two levels (15% and 30%) leading to a FM substitution of 25% and 50% and to a FO substitution of 36% and 72% respectively. No significant differences on growth performances were reported at the lowest level of inclusion allowing a valuable FO saving. St-Hilaire et al. (2007) suggested that above this level, the chitin contained in the pre-pupae may have decreased the digestibility, thus the availability of nutrients, resulting in lower fish performances. On the other hand, the dietary inclusion of HI meal lead to a modification of the dietary fatty acid profile (increase and decrease of saturated and polyunsaturated fatty acids, respectively) that could have influenced lipid digestibility. In the same trial, the authors studied the effects of a whole MD larvae meal included at 9.2% in the fish's diet (25% of FM substitution). The inclusion resulted in a decrease of production parameters (St-Hilaire et al. 2007). Renna et al. (2017) showed that a partially defatted HI larvae meal can be used as feed ingredient in rainbow trout diets up to 40% of inclusion level (50% of FM substitution) without impacting growth performance. Sealey et al. (2011) highlighted the possible influence of larva rearing substrate on the quality of the insect meal in a trial with rainbow trout. IM produced from HI larvae fed a diet enriched with fish offal performed better than IM produced from HI larvae fed a diet without the fish offal enrichment. Rainbow trout fed a diet with the enriched HI meal (at 50% FM replacement) performed as well as the control FM based diet, whilst the non-enriched HI meal performed lower at already 25% FM replacement.

A full fat TM larvae meal was tested as a FM substitution (up to 50%) in rainbow trout diets by Belforti et al. (2015). No significant changes in fish performance parameters were found up to 50% FM replacement. A reduced voluntary feed intake was reported with the increase of TM meal. The effects of dietary FM replacement (0%, 25%, 50% and 100%) by super worm (*Zophobas morio*) meal on rainbow trout fingerlings growth performance was investigated by Doğankaya (2017). Fish fed diets containing up to 25% of FM substitution performed better than the fish fed the control diet, while no differences were observed between 0% and 50% of FM substitution. Highest IM level induced a dramatic worsening in performance parameters.

Concerning marine species, Kroeckel et al. (2012) tested partially defatted HI pre-pupae meal in diets of juvenile turbot (*Psetta maxima*), and found a general worsening of performances at the inclusion levels higher than 33%. Moreover, authors found a decrease of feed intake with increasing HI meal incorporation, due to low palatability. Authors suggested that the presence of chitin might have influenced the feed intake, availability, and digestibility of the nutrients and therefore growth performance. Nevertheless, as HI was produced on local greenhouse waste streams, the authors concluded that it could be a sustainable alternative protein source in partial substitution of FM (Kroeckel et al. 2012). Karapanagiotidis et al. (2014) evaluated a pre-pupae full fat HI meal (crude protein, CP: 31.6%; either extract, EE: 27.2) in gilthead seabream (*Sparus aurata*) diets. Four diets were formulated substituting FM (0%, 9%, 17% and 25%) with HI meal at 0%, 9.5%, 19.4%

and 27.6% of HI inclusion. Fish fed diets containing HI meal recorded a significant decrease in final fish weight and WG due to a significant decrease of total feed consumption. On the other hand, feed conversion rate (FCR), protein efficiency ratio (PER) and protein retention as well as specific growth rate (SGR) parameters did not show differences among treatments.

Gasco et al. (2016) evaluated the effects of dietary inclusion of a full-fat TM larvae meal on European sea bass (*Dicentrarchus labrax*) juveniles. Dietary TM meal inclusion level of 50% led to a worsening of final body weight, WG, SGR and feeding rate (FR). Using the same substitution protocol and the same full-fat TM larvae meal, Piccolo et al. (2017) found improved final weight, SGR, PER and FCR in fish fed 25% of TM meal dietary inclusion.

The importance of insect processing becomes evident in a study by Lock et al. (2016). Two different HI meals (IMA and IMB), obtained through different nutrient isolation and processing techniques, were evaluated in diets for Atlantic salmon. IMA substituted 25, 50 and 100% of FM in the control diet while IMB was used at 25 and 100% FM replacement rate. Diets containing IMA performed equally well as the control group at all inclusion levels, however diets produced with IMB reduced fish performance parameters already at 25% FM replacement.

2.2 *Whole Body and Fillet Composition*

The influence of the use of IM on whole body composition (WBC) and fillet composition is not univocal. While an effect on the protein content has been shown (Belforti et al. 2015), the majority of the existing studies report a decrease in lipid and moisture increase in either WBC or fillet of fish when fed diets containing IM (St-Hilaire et al. 2007; Sealey et al. 2011; Kroeckel et al. 2012; Belforti et al. 2015). A reduced fat and energy digestibility of some IM could be the reason for the observed decreasing carcass fat content. Conversely, Akiyama et al. (1984) reported an increase in body energy reserves using earthworm. This effect was considered very valuable, as it could increase the fingerlings survival once released. Renna et al. (2017) found an increase of fat content in rainbow trout fillets using a partially defatted HI meal, but only at the highest level of inclusion. Similar results have been found in feeding Atlantic salmon diets containing high levels of defatted HI meal (Lock et al. 2017). High HI meal inclusion results in a higher saturated lipid content of the whole fish and fillet.

It has been ascertained that the dietary fatty acid (FA) profile dramatically influences the fish FA composition. IM are rich in saturated and monounsaturated FA, and do not contain the marine omega-3 long chain polyunsaturated FA (PUFA) such as eicosapentaenoic acid (EPA, C20:5 n-3) or docosahexaenoic acid (DHA, C22:6 n-3), which are well known for their beneficial effects on human health. St-Hilaire et al. (2007) reported a deterioration in fish nutritional quality using both MD and HI meals in diets for rainbow trout. The inclusion of IM led to a significant decrease of n-3 FA such as EPA and DHA, which is confirmed in other studies (Belforti et al. 2015; Gasco et al. 2016; Lock et al. 2016; Renna et al. 2017). Sealey et al. (2011) and Liland et al. (under revision) were able to modify the HI meal FA profile by enriching the larvae rearing substrate with fish offal and seaweed, respectively. Sealey et al. (2011) performed a trial with trout using the enriched HI meal and reported increased EPA (significant) and DHA (not significant) content in the fish. Up to 20% inclusion of a de-fatted HI meal, while maintaining FO in the diet, does not change the FA profile of trout compared to fish fed a control diet based on FM and FO (Renna et al. 2017).

2.3 Sensory Analyses

As the change of body composition and fatty acid profile can influence fish flavour, aroma and consumer acceptance (Turchini et al. 2011), some studies investigated the effect of diets containing IM on the sensory aspects of the fish fillet.

In a triangle difference test, untrained panellists did not highlight different sensory perception in samples of fillets of trout fed diets containing HI meal (enriched or not using fish offal in larva rearing substrate) compared to a FM based diet with no inclusion of HI pre-pupae meal (Sealey et al. 2011). Lock et al. (2016) investigated the sensory attributes of fillets of fish from diets containing FM (control) or 25% of inclusion of HI meal (100% of FM substitution) after 105 days of feeding. Trained panellists were asked to score attributes such as odour, taste and flavour, and texture, scoring them in a scale from 1 to 9. The analysis did not highlight any significant differences in odour, flavour/taste or texture between groups.

Borgogno et al. (2017) utilised descriptive analysis (DA) and Temporal Dominance of Sensations (TDS) to investigate the effects of replacing 25 and 50% of FM with HI meal on sensory properties of rainbow trout. Results indicated that diets significantly affected fillets sensory profile. In fact, significant changes in perceived intensity of aroma, flavour and texture descriptors as a function of diet composition was indicated by DA. Concerning TDS, the first sensations perceived as dominant were related to texture attributes, followed by flavours. Dominance of fibrousness (or toughness) decreased with the increasing of HI meal in diet. Boiled fish, algae flavours and umami taste clearly dominated the fish fed control diet dynamic profile. The onset of metallic flavour dominance characterized fish fed diets where FM was substituted by 25 and 50% of HI meal. No differences in physical parameters were detected. Principal component analysis highlighted the relationship between sensory attributes and physico-chemical parameters.

2.4 Chitin

It is commonly assumed that, due to its complex matrix, insect chitin is poorly digested by fish, albeit the chitinase activity has been observed in some fish species (Henry et al. 2015). It has been hypothesized that these matrix forms of chitin may reduce the access of chitinases or proteinases to their substrates and thus prevent the absorption of proteins and lipids by the intestine. As such, reducing lipid and protein digestibility resulting in a subsequent reduction in nutrient utilization and fish growth performance (Belforti et al. 2015; Henry et al. 2015; Gasco et al. 2016). Some studies investigated the nutrient apparent digestibility coefficients (ADC) of diets containing IM. In general a lower crude protein ADC is found compared to FM based diets (Kroeckel et al. 2012; Belforti et al. 2015). Nevertheless, not all studies find a decrease in ADC (Lock et al. 2016; Renna et al. 2017), highlighting once again the high variability in type and quality of insect meal available on the market.

Chitin as a stimulant of intestinal function, much like a fibre, has also been suggested. The use of alternative protein sources has often showed to induce histological changes of the fish gastrointestinal tract (Merrifield et al. 2009; Gai et al. 2012; Oliva-Teles et al. 2015). Very few studies have investigated this aspect using insect meals and results obtained so far are promising, as no negative effects are reported (Lock et al. 2016; Doğankaya 2017; Renna et al. 2017).

3 Feed Safety

Feed safety regulations are in place to secure that feed and feed materials do not pose any danger to human health, animal health or the environment, aiming to provide healthy and safe food products to the public. To achieve this, the European Union has set maximum allowed levels for undesirable substances in animal feed and feeding stuffs (EC Directive 2002/32 and amendments) (EU 2002). This covers a wide range of toxic compounds such as heavy metals, arsenic, polychlorinated biphenyl (PCBs), pesticides, plant and fungal toxins, amongst others. Safety considerations need to be taken into account when insects are destined to animal feed.

The uptake of contaminants by insects in the wild is well known, and they have therefore been successfully used as bioindicators for environmental pollution (Azam et al. 2015). The chemical safety of farmed insects for feed and food purposes has been reviewed (Belluco et al. 2013; Charlton et al. 2015; van der Spiegel et al. 2013). Although little data is available, major potential chemical hazards associated with farmed insects are heavy metals, and in particular cadmium. Accumulation of metals in insects is dependent on species, life stage, and metal considered. Larval stages of insects have been shown to contain higher concentrations of metals than adults (Lindqvist 1992; Diener et al. 2015).

Studies on the feed safety of farmed insects are very limited. Charlton et al. (2015) investigated a variety of insect species cultivated in several geographical locations, using different rearing substrates and conditions. The heavy metals cadmium, lead, mercury and the metalloid arsenic were found in larvae of MD, Blue bottle (*Calliphora vomitoria*), Blow fly (*Chrysomya spp.*) and HI. The EU maximum allowed levels for cadmium, lead, mercury and arsenic in complete fish feed and feed materials are set at 0.5, 5, 0.1, 2 and 2, 10, 0.1, 2 mg/kg (88% dry matter), respectively (EU 2002). The concentrations of these undesirables in the fly larvae analysed by Charlton et al. (2015) were all below the maximum limits.

During rearing, insects could accumulate contaminants present in their feeding media. However, only few studies have investigated the influence of different feeding substrates on metal accumulation in insect larvae (Biancarosa et al. 2017; Diener et al. 2015; Vijver et al. 2003). HI larvae accumulate heavy metals when these are present in the diet, and a direct correlation exists between dietary and larval metal concentrations. This was shown using either feeding substrates spiked with heavy metals (cadmium, lead or zinc) (Diener et al. 2015) or media naturally containing these undesirable elements, such as seaweeds (Biancarosa et al. 2017). Rearing insect larvae on substrates containing marine materials (seaweeds, tunicates, FM) also resulted in the uptake of cadmium, lead, mercury and arsenic in TM and super worms (Biancarosa et al. 2017). Vijver et al. (2003) previously documented accumulation of cadmium and lead in mealworms, when fed on soils contaminated with these contaminants.

The transfer of heavy metals and arsenic from feeding substrates to insect larvae highlights the need to carefully choose the material that is used to rear the larvae. However, there are currently big knowledge gaps related to the influence of different substrates on the metal content of farmed insects, thus further studies are required. Moreover, besides exploring the metal content of non-processed insects (e.g. whole larvae), documentation of the occurrence of these undesirable elements in processed larvae products (e.g. IM and insect lipid (IL)). Processing of the insect raw materials could potentially reduce metal contaminations prior to feeding. Further research is also needed to investigate whether heavy metals (or other potential risks) present in insects used for feed, are transferred to farmed fish.

Other chemical hazards may be present in rearing substrates for insects, thus may end up in insects and products thereof. In respect of the EU feed legislation (EC Directive 2002/32 and amendments) (EU 2002), Charlton et al. (2015) investigated the presence of dioxins, PCBs, polyaromatic hydrocarbons (PAHs), pesticide residues, veterinary drugs and mycotoxins in farmed insects destined to animal feed (house fly, blue bottle, blow fly and black soldier fly). These contaminants were found in the insect species tested, although in concentrations generally below current regulatory limits for these compounds in animal feed. Only the veterinary medicine nicarbazin (4,4′-dinitrocarbanilide) was detected at concentrations above the maximum allowed in animal feed (500 μg/kg) in one sample of MD, due to the use of contaminated animal manure as growth medium for the larvae.

Risks of this kind are minor in the EU, where feeding manure to farmed insects is currently prohibited. However, outside the EU other regulations apply. Insect meals produced outside the EU can be imported, although they have to fulfil the same requirements set by the abovementioned EC Directive when used in feeds. For some of the compounds detected by Charlton et al. (2015) (e.g. PAHs and the pesticide residue chlorphyrifos), no maximum limits are currently established for animal feed.

Microbiological hazards related to the use of insects for feed purposes have been taken into account in the first "Risk profile related to the production and consumption of insects as food and feed" by EFSA (2009). Like other famed animals, microorganisms can be naturally associated with insects (e.g. the microbiota in the guts or on the surface), or can be introduced during rearing processes. However, very few on the microbiological safety of insects for food and feed are currently available (Klunder et al. 2012) to support such risk analysis.

4 Conclusion

Studies on IM inclusion in aquafeeds so far have focused on FM replacement and growth performance, which is a logical first step for any new feed ingredient. Other aspects (both positive and negative) of IM on fish health are expected to be addressed over time, e.g. intestinal health, changes in microbiota, immunology, etc. There is also clearly an important role for insect processing (de-fattening, protein isolation, hydrolysation, etc.), which can affect the properties of a meal to a great extent. The effect of chitin is still under investigation, and no conclusive evidence exists of chitin functioning, as an anti-nutrient, immunostimulant, or any other function that has been proposed. Moreover, the role of the substrate on the quality of the meal is of a major importance as both the nutrient composition and content of undesirables are (partly) dictated by the composition of the insect feeding substrate. The approval of the EU Commission of the use of insect PAP in aquafeeds on the 13th December 2016 most likely triggers a surge in both demand and supply of IM, and exiting developments in this field of research are expected. Signals from feed producers indicate a strong interest in using this resource if volumes are reaching 40.000 MT or more, and if the price is competitive. The increase in IM demand will inevitably lead to a decrease in IM selling price that is until now, still not competitive if compared with other protein sources commonly used in aquaculture feeds. Finally, initial studies on consumer acceptance of insect-fed fish showed a positive consumer attitude (Verbeke et al. 2015; Mancuso et al. 2016), but additional studies will be needed when insect products reach the market.

References

Akiyama T, Murai T, Hirasawa Y, Nose T (1984) Supplementation of various meals to fish diet for chum salmon fry. Aquaculture 37:217–222

Azam I, Afsheen S, Zia A, Javed M, Saeed R, Sarwar MK, Munir B (2015) Evaluating insects as bioindicators of heavy metal contamination and accumulation near industrial area of Gujrat, Pakistan. Biomed Res Int. https://doi.org/10.1155/2015/942751

Barroso FG, de Haro C, Sanchez-Muros MJ, Venegas E, Martínez-Sánchez A, Pérez-Bañón C (2014) The potential of various insect species for use as food for fish. Aquaculture 422-423:193–201

Belforti M, Gai F, Lussiana C, Renna M, Malfatto V, Rotolo L, De Marco M, Dabbou S, Schiavone A, Zoccarato I, Gasco L (2015) *Tenebrio molitor* meal in rainbow trout (*Oncorhynchus mykiss*) diets: effects on animal performance, nutrient digestibility and chemical composition of fillets. Ital J Anim Sci 14:670–675

Belluco S et al (2013) Edible insects in a food safety and nutritional perspective: a critical review. Compr Rev Food Sci Food Saf 12(3):296–313

Biancarosa I, Liland N, Biemans D, Araujo P, Bruckner CG, Waagbø R, Torstensen BE, Lock EJ, Amlund H (2017) Uptake of heavy metals and arsenic in black soldier fly (Hermetia illucens) larvae grown on seaweed-enriched media. J. Sci. Food Agric. doi:10.1002/jsfa.8702

Borgogno M, Dinnella C, Iaconisi V, Fusi R, Scarpaleggia C, Schiavone A, Monteleone E, Gasco L, Parisi G (2017) Inclusion of *Hermetia illucens* larvae meal on rainbow trout (*Oncorhynchus mykiss*) feed: effect on sensory profile according to static and dynamic evaluations. J Sci Food Agric. Accepted on December 03–2016. https://doi.org/10.1002/jsfa.819

Charlton AJ, Dickinson M, Wakefield ME, Fitches E, Kenis M, Han R, Zhu F, Kone N, Grant M, Devic E, Bruggeman G, Prior R, Smith R (2015) Exploring the chemical safety of fly larvae as a source of protein for animal feed. JIFF 1:7–16

Diener S, Zurbrügg C, Tockner K (2015) Bioaccumulation of heavy metals in the black soldier fly, *Hermetia illucens* and effects on its life cycle. JIFF 1:261–270

Doğankaya L (2017) Effects of fish meal substitution with Super worm (*Zophobas morio*) meal on growth performance of rainbow trout fingerlings. TrJFAS 32(1):1–7. https://doi.org/10.18864/TJAS201701

EFSA (2009) Scientific opinion on arsenic in food EFSA panel on contaminants in the food chain (CONTAM). EFSA J 7(10):1351

EU (2002) Directive 2002/32/EC of the European Parliament and the Council of 7 May 2002 on undesirable substances in animal feed

Gai F, Gasco L, Daprà F, Palmegiano GB, Sicuro B (2012) Enzymatic and histological evaluations of gut and liver in rainbow trout, *Oncorhynchus mykiss*, fed with rice protein concentrate based diets. J World Aquacut Soc 43:218–229, ISSN: 0893-8849

Gasco L, Henry M, Piccolo G, Marono S, Gai F, Renna M, Lussiana C, Antonopoulou F, Mola P, Chatzifotis S (2016) *Tenebrio molitor* meal in diets for European sea bass (*Dicentrarchus labrax* L.) juveniles: growth performance, whole body composition and in vivo apparent digestibility. Anim Feed Sci Technol 220:34–45

Henry M, Gasco L, Piccolo G, Fountoulaki E (2015) Review on the use of insects in the diet of farmed fish: past and future. Anim Feed Sci Technol 203:1–22

Karapanagiotidis IT, Daskalopoulou E, Vogiatzis I, Rumbos C, Mente E, Athanassiou CG (2014) Substitution of fishmeal by fly *Hermetia illucens* prepupae meal in the diet of gilthead seabream (*Sparus aurata*). HydroMedit 2014, November 13–15, Volos, Greece

Klunder HC et al (2012) Microbiological aspects of processing and storage of edible insects. Food Control 26(2):628–631

Kroeckel S, Harjes AGE, Roth I, Katz H, Wuertz S, Susenbeth A, Schulz C (2012) When a turbot catches a fly: evaluation of a pre-pupae meal of the black soldier fly (*Hermetia illucens*) as fish-meal substitute-growth performance and chitin degradation in juvenile turbot (*Psetta maxima*). Aquaculture 364-365:345–352

Liland N, Biancarosa I, Araujo P, Biemans D, Bruckner C, Waagbø R, Torstensen B, Lock EJ. (under revision) Modulation of nutrient composition of black soldier fly (*Hermetia illucens)* larvae by feeding seaweed-enriched media. JIFF

Lindqvist L (1992) Accumulation of cadmium, copper, and zinc in five species of phytophagous insects. Environ Entom 21(1):160–163

Lock EJ, Arsiwalla T, Waagbo R (2016) Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. Aquac Nutr 22:1202–1213

Lock EJ, Biancarosa I, Waagbø R. (2017) New feed ingredients for Atlantic salmon. The 11th Symposium of World's Chinese Scientists on Nutrition and Feeding of Finfish and Shellfish. 23–27 October, Huzhou, People's Republic of China

Makkar HPS, Tran G, Heuze V, Ankers P (2014) State-of-the-art on use of insects as animal feed. Anim Feed Sci Technol 197:1–33

Mancuso T, Baldi L, Gasco L (2016) An empirical study on consumer acceptance of farmed fish fed on insect meals: the Italian case. Aquacult Int 24:1489–1507. https://doi.org/10.1007/s10499-016-0007-z

Merrifield DL, Dimitroglou A, Bradley G, Baker RTM, Davies SJ (2009) Soybean meal alters autochthonous microbial populations, microvilli morphology and compromises intestinal enterocyte integrity of rainbow trout, *Oncorhynchus mykiss* (Walbaum). J Fish Dis 32:755–766

Oliva-Teles A, Enes P, Peres H (2015) Replacing fishmeal and fish oil in industrial aquafeeds for carnivorous fish. In: Davis DA (ed) Feed and feeding practice in aquaculture. Woodhead Publishing, Cambridge, pp 203–233

Piccolo G, Iaconisi V, Marono S, Gasco L, Loponte R, Nizza S, Bovera F, Parisi G (2017) Effect of Tenebrio molitor larvae meal on growth performance, in vivo nutrients digestibility, somatic and marketable indexes of gilthead sea bream (Sparus aurata). Anim Feed Sci Technol. https://doi.org/10.1016/j.anifeedsci.2017.02.007

Renna M, Schiavone A, Gai F, Dabbou S, Lussiana C, Malfatto V, Prearo M, Capucchio MT, Biasato I, Biasibetti E, De Marco M, Zoccarato I, Gasco L (2017) Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens L.*) larvae meal as ingredient for rainbow trout (Oncorhynchus mykiss Walbaum) diets. J Anim Sci Biotechnol. 8:57 DOI: 10.1186/s40104-017-0191-3

Rumpold BA, Schülter OK (2013) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57:802–823

Sánchez-Muros MJ, Barroso FG, Manzano-Agugliaro F (2014) Insect meal as renewable source of food for animal feeding: a review. J Clean Prod 65:16–27

Sealey WM, Gaylord TG, Barrows FT, Tomberlin JK, McGuire MA, Ross C, St-Hilaire S (2011) Sensory analysis of rainbow trout, *Oncorhynchus mykiss*, fed enriched black soldier fly prepupae, *Hermetia illucens*. J World Aquacult Soc 42:34–45

St-Hilaire S, Sheppard C, Tomberlin JK, Irving S, Newton L, Mc Guire MA, Mosley EE, Hardy RW, Sealey W (2007) Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. J World Aquacult Soc 38:59–67

Turchini GM, Ng WK, Tocher DR (eds) (2011) Fish oil replacement and alternative lipid sources in aquaculture feeds. Taylor & Francis/CRC Press, Boca Raton, p 533

van der Spiegel M, Noordam MY, van der Fels-Klerx HJ (2013) Safety of novel protein sources (Insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. Compr Rev Food Sci Food Saf 12(6):662–678

Verbeke W, Spranghers T, De Clercq P, De Smet S, Sas B, Eeckhour M (2015) Insects in animal feed: acceptance and its determinants among farmers, agriculture sector stakeholders and citizens. Anim Feed Sci Technol 204:72–87

Vijver M, Jager T, Posthuma L, Peijnenburg W (2003) Metal uptake from soils and soil–sediment mixtures by larvae of *Tenebrio molitor* (L.) (Coleoptera). Ecotoxicol Environ Saf 54:277–289

Mealworm Larvae Production Systems: Management Scenarios

Frédéric Maillard, Catherine Macombe, Joel Aubin, Hedi Romdhana, and Samir Mezdour

Abstract This chapter highlights a part of the work carried out within the framework of the DESIRABLE project (*"DESIgning the Insect bioRefinery to contribute to a more sustainABLE agro-food industry")*, funded by the French National Research Agency (ANR). Here, our aim is to present original research results to operators willing to implement insect-based value-chains for feed, and to decision-makers eager to understand the main related stakes. Our tasks focused on the practical organization of mealworm larvae (*T. molitor*) raising and processing, in middle-sized (about 400 tons of larvae per year) and very large-sized (about 2000 tons per year) processing systems. The objective was to monitor health hazards and to organize production chains in the best way possible, in order to make human operations smooth and efficient, while accounting for the physiological needs of insects. In this chapter, we have designed in detail relevant insect "group management" for middle-sized farming systems, some being focused on farrow-to-wean stage, and others specialized in insect fattening. We highlight improvement avenues, which would deserve additional developments in the future. For very large-sized production systems, we suggest adequate group management, and we identify the technical difficulties which hamper the setting-up of such huge integrated systems, to date. We present how we have established three different kinds of processes for an annual production of 10,000 tons, from larvae to flour. We also present the features of intermediate by-products, by generating data evaluating the flows of energy and matter, thus leading the way towards a possible economic feasibility. We raise some remaining questions to be explored. We also provide directions for environmental and economic evaluation. These results show the way for future scientific investigations, in accordance with sound social concerns.

F. Maillard · C. Macombe
IRSTEA, UMR ITAP, Groupement de Montpellier, Domaine de Lavalette, F-34196 Montpellier Cedex 5, France

J. Aubin
INRA, UMR1069, Sol Agro et hydrosystème Spatialisation, Rennes, France

H. Romdhana · S. Mezdour (✉)
AgroParisTech, UMR1145 Ingénierie Procédés Aliments, Massy, France
e-mail: samir.mezdour@agroparistech.fr

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_17

1 Introduction

In a context of increasing scarcity of resources, insects - so far underexploited as a commodity- could be a source of raw materials for food and feed (FAO 2014). This, at least, is the postulate of the DESIRABLE project (Azagoh et al. 2015), which has been funded by the French National Research Agency (ANR) since 2013 within the framework of its Sustainable Food Systems program. Given the present context of growing demand for meat and short supply of cultivable land, the stock market value of proteins for animal feed has greatly increased over the last few years (Perez Galvez 2009). The recommendations of the Food and Agriculture Organization of the United Nations (FAO) about how to feed the world in 2050 include the development of protein production (Berk 1992; Godfray et al. 2010) and notably "Protein-Rich Materials" (PRM) obtained from insects and used in livestock rearing and the food industry. Insects do indeed seem to be a credible and environment-friendly solution to counter the shortage of PRMs. The aim of the DESIRABLE project (from January 2013 to September 2017), is thus to evaluate the performance of the larvae of mealworm (*T. molitor*) for feeding fish and poultry (Ramos-Elorduy et al. 2002). The project also includes a social and environmental study of the impact of the insect route as a food resource (for animal feed).

The ambition of the DESIRABLE project is to cover one entire new insect-based value-chain, from the sourcing to feed the insects, which will be transformed into PRM, through to final consumption in poultry and fish farms. In this chapter, we deal only with insect rearing and processing. The systems described hereafter stem from scenarios elaborated by the partners of the DESIRABLE project. It should be noted that the technical and management outputs depicted are valuable, whatever the final destination of the PRM. Our work originality is that we design the whole system articulating farms and transformation units, for industrial size. More accurately, the challenge set by DESIRABLE is to design systems providing 10,000 tons of insect meal for feed per year.

The first and second sections deal with management of insects rearing, in middle-size and large size farms. The third section displays the organization of processing to get insect meal and oil, when it comes to industrial scale. The fourth section is devoted to the research questions raised by the studies.

First, we recall the cycles of *T. molitor*. Table 1 and Fig. 1 sum up physiological features of growth and reproduction cycles (Morales-Ramos et al. 2012), while matching them with rearing stages (Van Broekhoven et al. 2015). The calendar below stems from a reference insect farm (H), and was collected within the framework of the DESIRABLE project in 2015 and 2016. Table 1 displays the management of insect livestock week by week. The whole cycle (including reproduction and growth) lasts 14 weeks. One new cycle (with new insects) starts every week. During growth periods, larvae are fed only twice a week, on Mondays and on Thursdays.

Photos of the different operations presented in Table 1 are visible in Fig. 1. Indeed, Fig. 1 shows both the physiological cycle of *T. molitor*, and the different rearing steps, illustrated by photos from Frédéric Maillard, taken in the reference farm H.

Table 1 Rearing steps of *T. molitor* at French farm H (our own collection of data)

Day	Week	Key steps at H
Tuesday	S1	Collecting imagos[a]
Wednesday	S1	Seeding boxes with imagos
Wednesday	S2	Giving beet pulp to imagos
	S2-S3	Screening imagos and substrate with eggs
	S3	Eggs hatching
Tuesday	S4	Concentration in boxes
		Birth step duration: 5 weeks and 1 day
Thursday	S4	1st feeding of PL
	S5	Monday and Thursday feedings
	S6	Monday and Thursday feedings
	S7	Monday and Thursday feedings
	S8	Monday and Thursday feedings
Monday	S9	PL sifting and feeding
	S10	Monday and Thursday feedings
	S11	Monday and Thursday feedings
	S12	Monday and Thursday feedings
Monday	S13	2 siftings before processing and nymphs screening
Tuesday	S13	Putting nymphs in boxes
	S14	Nymphs on hold
Tuesday	S15 = S1	Collecting imagos etc.

[a]Imago: the young adult insect, ready to breed; *PL* small larvae, *GL* large larvae. Sn means the week number n of the cycle

As planned in the DESIRABLE project, we designed theoretical scenarios (presented in Sects. 1 and 2) with the concern of staying as close as possible to plausible and feasible projects.

2 Practical Management of Middle-Size Production Systems of *T. molitor*

2.1 General Overview

In this section, we have relied on our visits made to farmers and the data collected from them on these occasions. The rearing cycle is split into farms performing the farrow-to-wean step (getting breeders and eggs) and farms fattening the insects (from eggs to marketable larvae).

One cooperative (with 17 employees) is the outlet of middle-size farm workshops (from 92 fattening farms articulated with 23 farrow-to-wean farms), set in existing agriculture farms. The cooperative is located in a French region called “Pays de la Loire”, close to both raw materials for feeding and outlets for insect

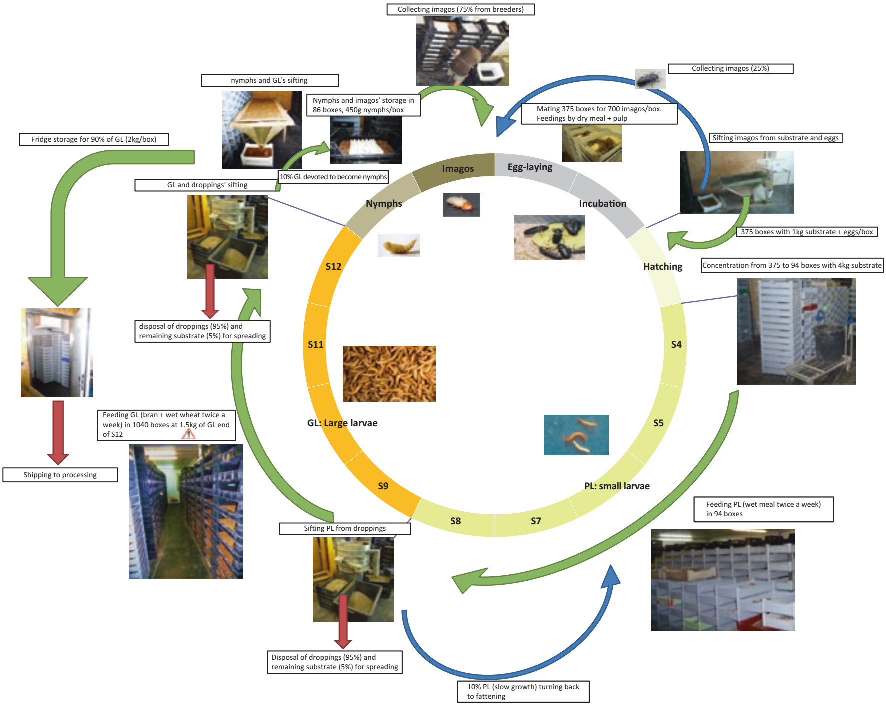


Fig. 1 Physiological and rearing cycles in a *T. molitor*

meal (through poultry and trout farms). The cooperative stores ingredients for feed devoted to insects, and house larvae processing. The farms are scattered within 150 km around the cooperative. Thus transportation of the living larvae up to the cooperative lasts one or two hours only. The suggested organization is not optimal in terms of rearing buildings occupation, but it allows for streamlining tasks and limiting health hazards (Eilenberg et al. 2015). The insects rearing phase takes place in two types of farm workshops: farrow-to-wean farms, which achieve the whole cycle to provide eggs, and fattening farms, which grow and fatten small and large larvae (see Table 2).

2.2 *Fattening Management*

Fattening farms provide only large larvae devoted to processing and organic wastes. The standard farm consists of 4 buildings (the most ordinary easy-to-find poultry type), of 400 m^2 each, automated for feeding. Three people are employed, corresponding to two equivalent full-time workers.

Table 2 Rearing steps at farrow-to-wean and at fattening workshops

Day	Week	At farrow-to-wean	At fattening
Tuesday	S1	Collecting imagos	
Wednesday	S1	Seeding boxes with imagos	
Wednesday	S2	Giving beet pulp to imagos	
	S2-S3	Screening imagos and substrate with eggs	
	S3	Eggs hatching	
Tuesday	S4	Concentration in boxes	
Birth step duration: 5 weeks and 1 day			
Thursday	S4	1st feeding of PL	1st feeding of PL
	S5	Monday and Thursday feeding	Monday and Thursday feeding
	S6	Monday and Thursday feeding	Monday and Thursday feeding
	S7	Monday and Thursday feeding	Monday and Thursday feeding
	S8	Monday and Thursday feeding	Monday and Thursday feeding
Monday	S9	PL sifting and feeding	PL sifting and feeding
	S10	Monday and Thursday feeding	Monday and Thursday feeding
	S11	Monday and Thursday feeding	Monday and Thursday feeding
	S12	Monday and Thursday feeding	Monday and Thursday feeding
Monday	S13	2 siftings before processing and nymphs screening.	1 sifting before processing
Tuesday	S13	Putting nymphs in boxes	
	S14	Nymphs on hold	
Tuesday	S15 = S1	Collecting imagos etc.	
Cycle duration	14 weeks		8 weeks and 5 days

PL small larvae, *GL* large larvae

Fattening farms receive eggs from farrow-to-wean farms (see Sect. 2.3) on the Wednesday of Week 4. They raise larvae on substrate (mainly from bran) during 4 weeks and 5 days, then sift them and put them again on another substrate during 4 weeks. Lastly, large larvae are sifted and sent (by the cooperative's specially designed lorry) for processing, on the Monday of Week 13. If one includes one week for sanitary fallowing (Eilenberg et al. 2015), the cycle lasts 4.7 + 4 + 1 = 9.7 weeks. During 1 year (52 weeks) we can put 52/9.7 = 5.3 insects' batches per building.

There are 4 buildings in each fattening farm. Each building houses 5.3 insects' batches. The 4 buildings therefore house 21 batches per year. For managing work organization smoothly, successive batches initiations are spaced by one week (see Fig. 2).

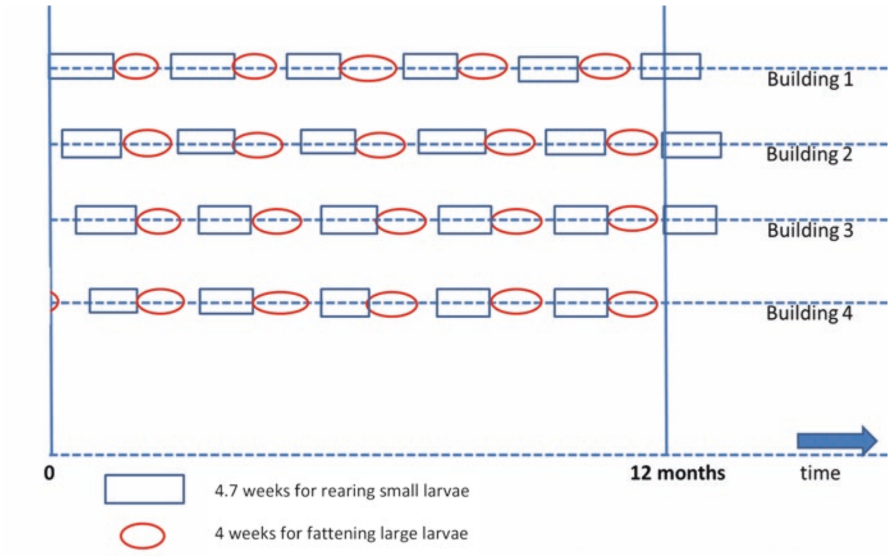


Fig. 2 Management by batch for fattening farms with 4 buildings

The larvae remain in the same container until the end. They are sifted during Week 9, to prevent infestation by *Anagasta kuehniella* (Mediterranean flour moth), to avoid boxes overflow, and to screen larvae that are too small (about 10% are transferred to the next batch). Therefore, each building is occupied only for one quarter of its surface during the first 4 weeks and 5 days, and afterwards fully occupied during 4 weeks.

From our calculations, we can fit 13,312 boxes in one 400 m^2 building. As one box collects 1.5 kg of larvae, each batch delivers on average 13,312 boxes × 1.5 kg = 19,968 kg. Accordingly, during 1 year, 4 buildings provide 21 batches x 19,968 kg = 419 tons of larvae.

2.3 *Farrow-to-Wean Management*

A farrow-to-wean workshop is automated to deliver feedings to insects, and managed by three to four workers, who correspond to 2.5 full-time employees.

Slow-growing larvae will not be transferred to the next batch, because it is not worth keeping them for breeding. One can make the last sifting more quickly than at H farm (carrying out one rough sifting followed by one screening on layer of Hessian), or sifting earlier than in H, to be sure that no larva reaches the sensitive step of pupation yet. Figure 3 illustrates the follow-up of steps at a farrow-to-wean farm.

At farrow-to-wean farms, we suggest to specialize rooms for eggs-laying/hatching and for the rest.

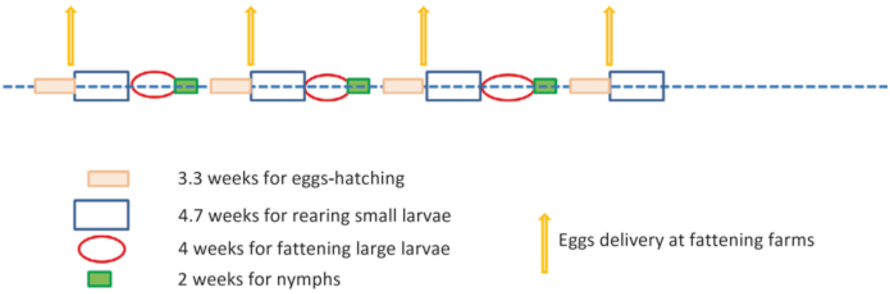


Fig. 3 Follow-up of steps at farrow-to-wean farms

Type (A) buildings house the reproduction step (Morales-Ramos et al. 2012), with succession of eggs-laying/hatching periods lasting 3 weeks and 2 days, and separated by a 5-day health fallow. Accordingly, (52 /4 =) **13 batches** take their turn regularly in the same building, during the year.

Type (B) buildings house growing and fattening steps for larvae (including sifting in Week 9) and nymph rearing. Insects remain in the same box throughout all the stages. It lasts 10 weeks and 5 days. Adding 1 week and 2 days for a health fallow, we can therefore fit 52/12 = 4.3 batches successively in the same room, during 1 year.

To articulate provision paces of (A) and (B), it is mandatory to use 3 fattening and nymphs rooms (called B1, B2 and B3 in Fig. 4) to receive the delivery from one eggs-laying and hatching room (called A in Fig. 4).

The average farrow-to-wean farm includes 4 buildings (A) (with single 400 m^2 room each) and for 2 buildings (B) including 6 rooms of 66 m^2 (Fig. 5). The total building surface are 2400 m^2.

Based on our calculations, we can fit 30,780 boxes in one building (A). As each box supplies about 1 kg of substrate, one building (A) will supply about 31 tons of substrate per batch. The annual production per building (A) is 13 batches × 30.78 t = 400 tons of substrate. Accounting for 4 buildings (A), the whole yield is 4 × 400 t = 1600 tons per farm and per year.

2.4 *Summary of the Middle-Size Farms System*

From farrow-to-wean farms, farmers send boxes containing substrate with eggs to fattening farms, at the pace of 4 deliveries, every month, all year long. The 4 deliveries can be separately set at any moment during the month, because the 4 buildings (A) operate independently.

One building (A) and its follow-up in (B) finally generate 36,000 kg of larvae per batch. Nevertheless, 9/10 of larvae (32,400 kg) will be raised by fattening farms, while 1/10 will be raised by farrow-to-wean farms. One farrow-to-wean farm as a whole supplies 1600 tons of substrate per year, which finally generates 1684 tons of

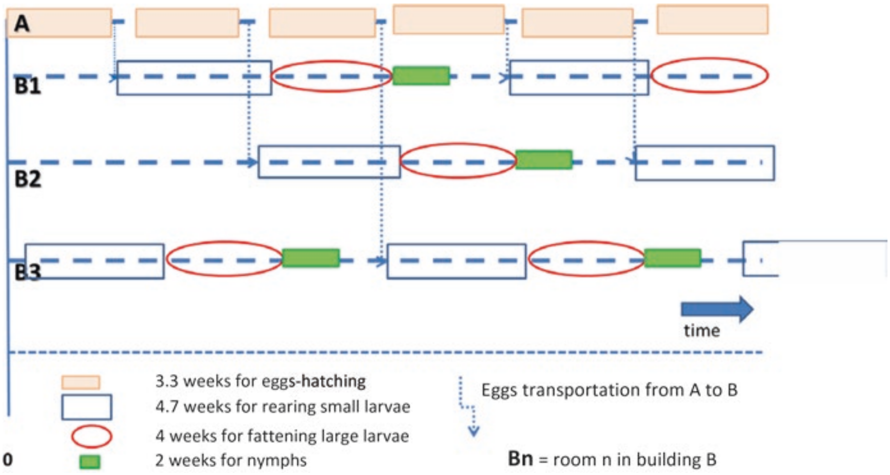


Fig. 4 Batches articulation in building (A) and (B)

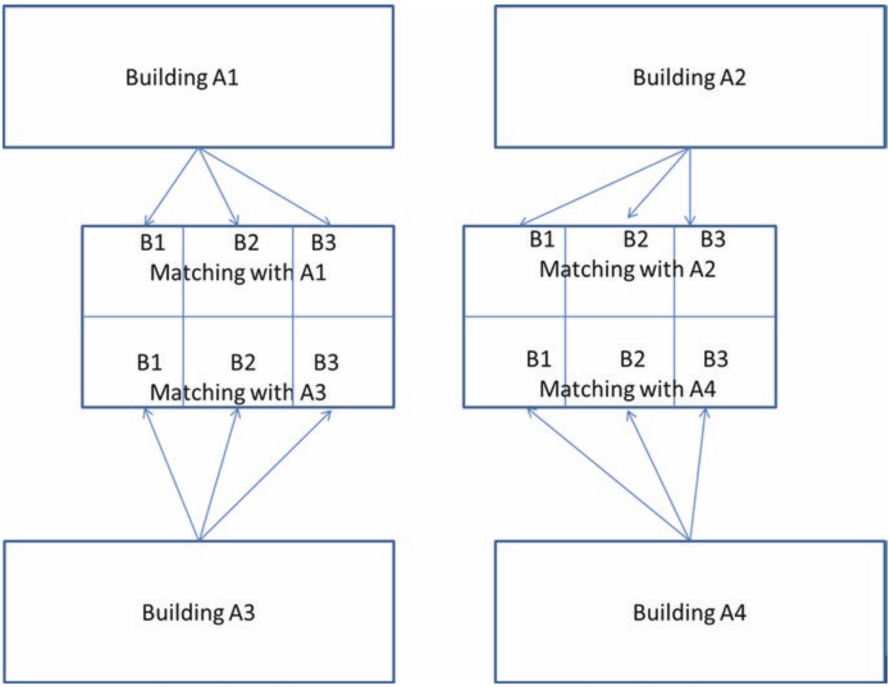


Fig. 5 Buildings (A) and (B) organization at farrow-to-wean farm

Table 3 Features of average farrow-to-wean farms and fattening farms

Features	Average farrow-to-wean farm	Average fattening farm
Size (buildings surface)	2400 m^2	1600 m^2
Buildings surface	4 × 400 m^2 egg-laying + 2 × 6 rooms 66 m^2	4 × 400 m^2
Number of batches per 400 m^2 building	13	5.3
Number of batches per year	4 × 13 = 52	4 × 5.3 = 21
Equivalent full time staff	2.5	2
Yield (harvest) per batch	31 t substrate with eggs	19,968 kg of sold larvae
Yield per 400 m^2 building	403 t substrate	105 t of sold larvae
Yield for the whole farm	1612 t substrate	419 t of sold larvae
Deliveries	52 harvests of substrate and eggs (4 each 4 weeks).	21 harvests of sold larvae per year

larvae for processing at the fattening farm. As one fattening farm provides 419 tons of larvae to be sold per year, one farrow-to-wean farm can supply 1612/419 = 4 fattening farms (Table 3).

To reach the supply of 10,000 tons of flour from insects per year, it is necessary to set-up 92 fattening farms and 23 farrow-to-wean farms.

3 Practical Management in Large-Size Production Systems of *T. molitor*

3.1 General Overview

A limited liability company manages the bio-refinery, integrating livestock farming and processing at the same location. The business model rests upon purchasing cheap feed ingredients (e.g. incorporation of potatoes peels), and selling insect meal, oil, and organic wastes. All the workers are employees of the company. Some are multi-skilled technicians working in farming sections, others are processing technicians (including laboratory technicians) and others are sales representatives to find potential purchasers.

The bio-refinery includes 6 sections:

– Processing of insects into flour and oil
– Fattening of larvae
– From nymphs to eggs-hatching
– Reception and storage for ingredients of insects' feed
– Processing of feed for the insects at different stages
– Storage of droppings and water treatment plant

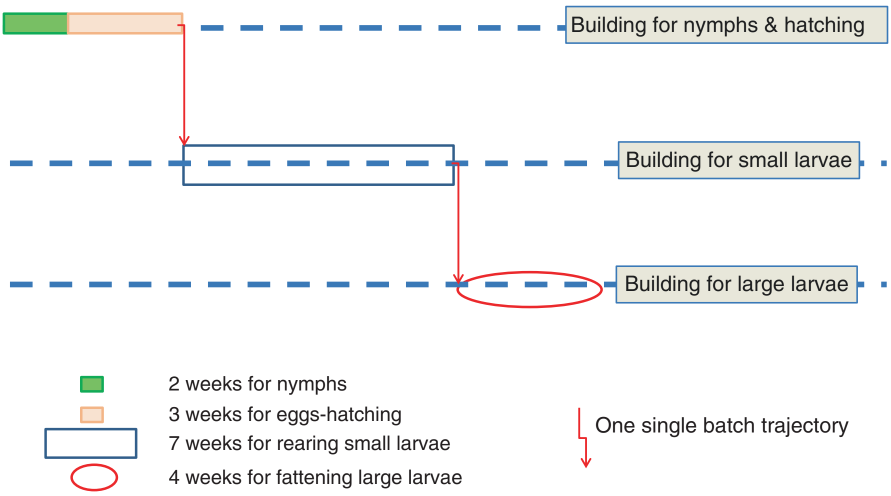


Fig. 6 Production cycle of larvae in the integrated system

In order to work out a rearing management method, we have drawn information from trials conducted in a reference farm (Y) (surveyed during DESIRABLE project), from literature (Van Broekhoven et al. 2015) and above all from other kinds of agriculture and rearing practices.

Figure 6 shows the comprehensive cycle of producing larvae. It displays three stages within the farming section. Indeed, we have decided to split units into three stages, in order to:

- optimize the occupancy of buildings. Thus space/time is the chief limiting factor here,
- push automation to its maximum limit,
- limit consequences of potential epizooty (Eilenberg et al. 2015).

The common principle being implemented in all stages is start one batch every week. We plan one health fallow in each room. While starting one batch every week, we choose the duration of health fallows so as to get a total duration of building occupancy as a multiple of the week. Figure 7 displays the duration of the buildings occupancy, including health fallows.

– For the stage "from nymphs to eggs-hatching": 2 + 3.3 + 0.7 (health fallow) = 6 weeks
– For the stage "small larvae growing": 4.7 + 1.3 (health fallow) = 6 weeks
– For the stage "large larvae fattening": 4 + 1(health fallow) = 5 weeks

In the next paragraphs (2.2, 2.3, 2.4) we present proposals for livestock management.

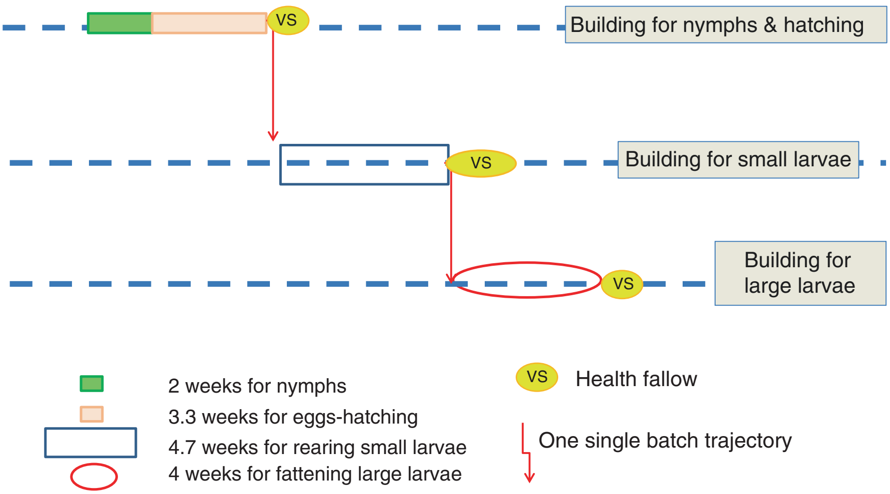


Fig. 7 Rearing buildings occupancy by one batch of insects

3.2 Large Larvae Fattening Management

Each Monday, one fattening room gets one batch of small larvae. After fattening for 4 weeks, the larvae reach the processing unit, on the Monday of Week 13. The fattening room is cleaned, disinfected, and remains closed during the health fallow week. Therefore, in the same fattening room, it is possible to accommodate successively 10.4 batches per year. To get one batch every week, one therefore needs 5 rooms (see Fig. 8).

Fattening of large larvae supplies 5 × 10.4 = 52 batches per year. They provide the basis to routinely supply the annual production of the bio-refinery, also including larvae for breeding (10% of the total amount of larvae). Accordingly, the total quantity of large larvae to be produced is 42,734 tons per year.

3.3 Small Larvae Growth Management

Each batch of small larvae remains in one room during 6 weeks, including health fallow (see Fig. 9). It is therefore possible to accommodate successively in the same room 8.67 batches during 1 year. In order to start one small larvae batch each week, we need 6 rooms (because 6 × 8.67 =) 52 batches.

The pace of large larvae supplies to processing unit (one batch each week) reinforces the pace of small larvae supplies to fattening units, and so the pace of collecting substrate with eggs, which is one each week as well.

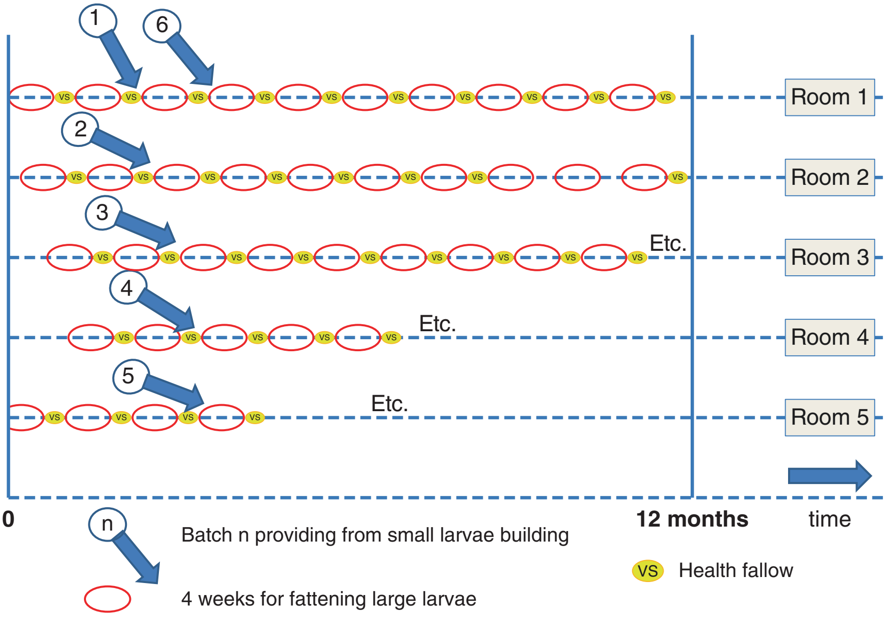


Fig. 8 Distribution of large larvae batches in the five rooms, during one year

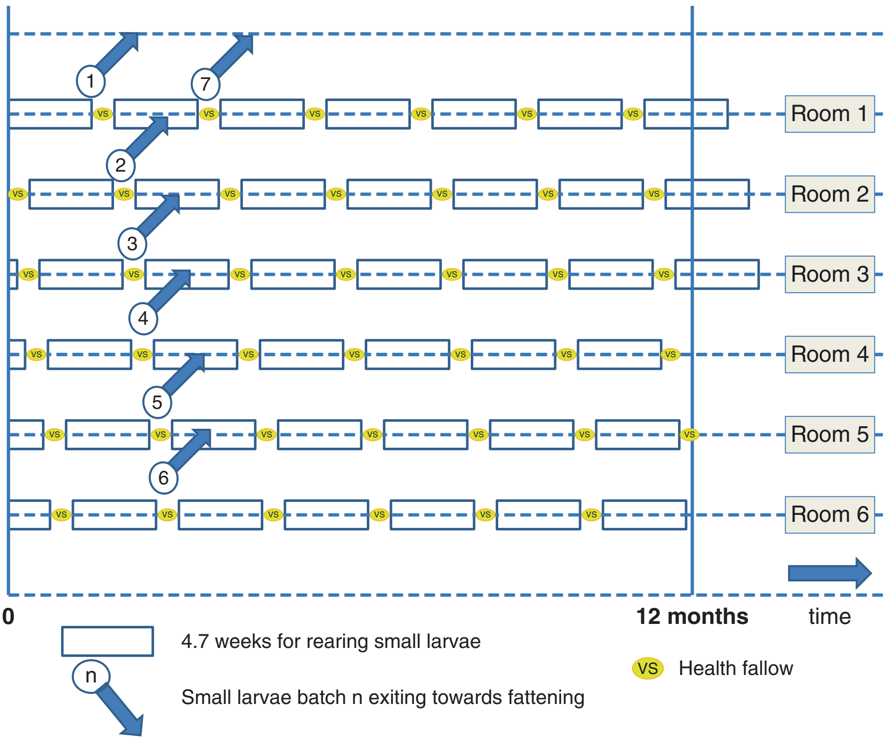


Fig. 9 Management of the 6 rooms for growing small larvae, per year

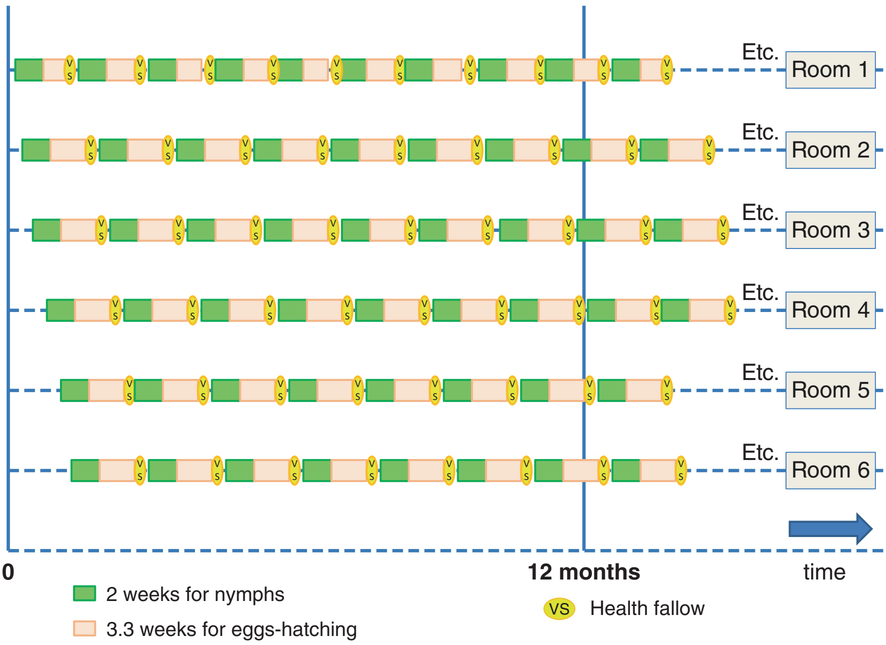


Fig. 10 Management of the 5 rooms of nymphs and eggs hatching, per year

3.4 *From Nymphs to Eggs-Hatching Management*

Each batch of nymphs (meaning imagos in the making) occupies one room during 6 weeks. We can therefore successively accommodate 8.67 batches in the room during 1 year. In order to start one nymphs batch each week, we need 6 rooms (because 6 × 8.67 =) 52 batches. Figure 10 displays the functioning of the nymphs to eggs hatching-division during 1 year.

3.5 *Summary of the Large-Size Farms System*

Table 4 sums up the features of the three rearing divisions, which enable their articulation in accordance with the common pace of one batch starting each week.

In practice, we suggest to divide the whole system into 20 farms producing the same quantity of large larvae, that being 42,744 t/20 = 2137 tons per year. For sanitary reasons, the first two farms are insulated from all others. Both involve all the rearing stages, and together supply the 4274 t of large larvae devoted to breeding for the whole integrated system. They supply substrate with eggs to the other 18 farms, thanks to dedicated lines. The other 18 farms grow and fatten larvae only, without supplying breeding section. The 18 farms are in close relationships with the processing unit. Figure 11 illustrates a possible pattern for the whole integrated system.

Table 4 Features of batch management in the divisions

Division	Large larvae	Small larvae	From nymphs to eggs-hatching
Duration of room occupation per batch	5 weeks	6 weeks	6 weeks
Number of batches per room	10.4	8.67	8.67
Number of rooms	5	6	6
Number of batches per year	52	52	52
Supplied quantities per batch	822 t of large larvae: 740 t for processing and 82 t for breeding	384 t (estimation) of small larvae	703 t of substrate with eggs
Annual quantity produced (52 batches)	42,744 t of large larvae: 38,470 for processing and 4274 t for breeding	19,968 t (estimation) of small larvae	36,556 t of substrate with eggs

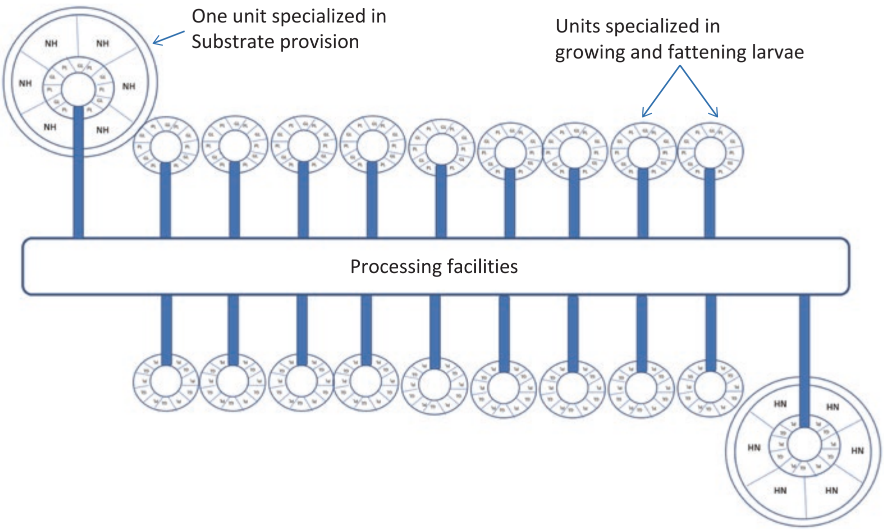


Fig. 11 Pattern for the spatial organization of the integrated bio-refinery

Other research carried out on the spatial and temporal organization of the integrated bio-refinery yielding 10,000 tons of flour from insects per year has not been detailed within this chapter. Other details can be found in the deliverable reports of the ANR project.

4 Scenario for Processing *T. molitor* Larvae

4.1 General Overview

Various studies (Iroko 1982; Farina et al. 1991; Ramos-Elorduy et al. 2002) aiming at the promotion of insect-based PRMs for animal feed have been conducted during the past few years. These studies highlight the zootechnical and environmental interest of these products in feeding farm animals (Sheppard et al.1994; Ramos Elorduy et al. 2002; Newton et al. 2005). Indeed, insect larvae are particularly interesting in terms of nutrition for farm animal as they contain proteins, essential amino-acids, lipids and calcium.

As of today, insect meal is being produced in small quantities for experimental purposes, and its price is therefore too high for economic development at this stage. As far as we know, technical and economic data relating to an industrial scale production and marketing are non-existent or non-accessible. Only small-scale pilot-projects or demonstrators are currently functioning in Europe, often initiated by private operators and non-accessible. The goal driving all these endeavours is to eventually develop production units that can deliver thousands of tons of insect meal annually. However, a large-scale industrial feasibility with competitive costs of production remains to be demonstrated.

The scope of this section is to generate data in order to conduct a preliminary evaluation of the technical feasibility and the economic relevance of the transformation of insect larvae *(T. molitor)* into flour, following production patterns that take into account the actual needs of the fish-farming and poultry industries.

Our goals are first, to propose different processes to produce 10,000 tons of mealworm flour annually with larvae, and secondly, to quantify their respective flows of energy and matter. The flours obtained are of two different types, whole meal flour and one that is partially de-lipidated. Results are based on selected pilot-trials and interaction with equipment suppliers.

4.2 Process Flowsheet and Scenarios Description

The choice of transformation process (either mechanical, chemical or biotechnical), and the resulting quality of products is crucial to satisfy the needs of users (some expect insect flour, insect-protein isolates or hydrolysates, while some others may need more specific purified high value-added molecules). Different processes designed to make PRMS exist. The processes are more or less adapted to the industrial scale. They are also more or less environment-friendly (for example using non-food grade toxic solvents), and more or less economically optimized (high cost of finished products). The nutritional quality can be compromised by denaturated proteins. These problems can be exemplified in the already existing fish-meal (Perez Galvez 2009) and soya-meal industries (Berk 1992) that resort, among others, to thermomechanical treatments such as pressing and drying.

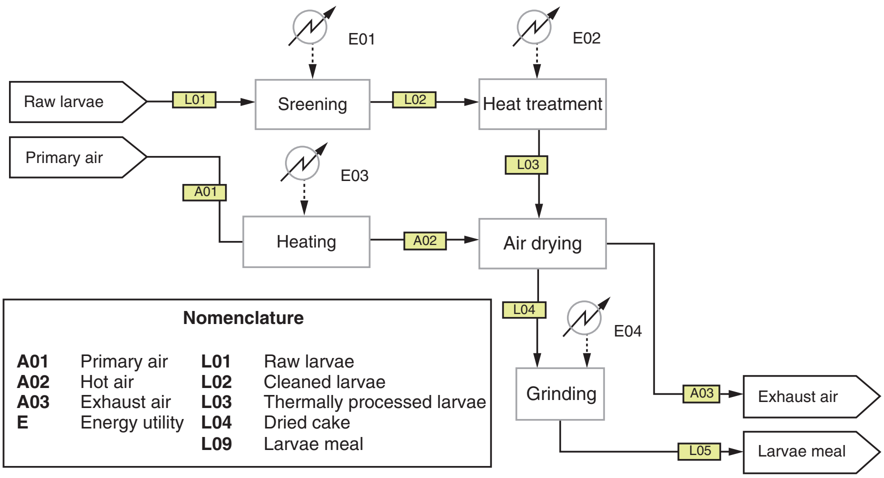


Fig. 12 Drying of whole larvae (scenario 1)

The processes that include thermomechanical treatments (drying, pressing etc.) are generally used in the fish-meal (Perez Galvez 2009) and soya-meal industries (Berk 1992).

4.2.1 Process Flowsheet

The flow diagrams for larvae processing plants are given in Figs. 12, 13 and 14 corresponding respectively to three scenarios:

Scenario 1: drying of whole larvae
Scenario 2: fractionation of the whole larvae into oil, de-oiled liquor and dried meal phases
Scenario 3: fractionation of the whole larvae into oiled and dried meal phases

4.2.2 Scenarios description

The scenarios are intended to produce a larvae meal that can be stored safely for at least 1 year, depending on processing methods, packaging and storage facilities. The drying of whole larvae involves removing about 85–90% of the initial moisture content of the raw larvae (i.e. 55–65% wet base). The dried product includes 3 main biofunctional compounds: proteins, lipids and chitin. These phases can be separated and purified in order to produce high added-value ingredients. Both scenarios 2 and 3 involve the production of protein flour that is partially de-oiled by removing a part of the lipid phase.

The first scenario (Fig. 12) involves four steps: first, the raw larvae L01 (60–65% moisture, wet base (wb)) are screened by a vibrating conveyor to remove organic

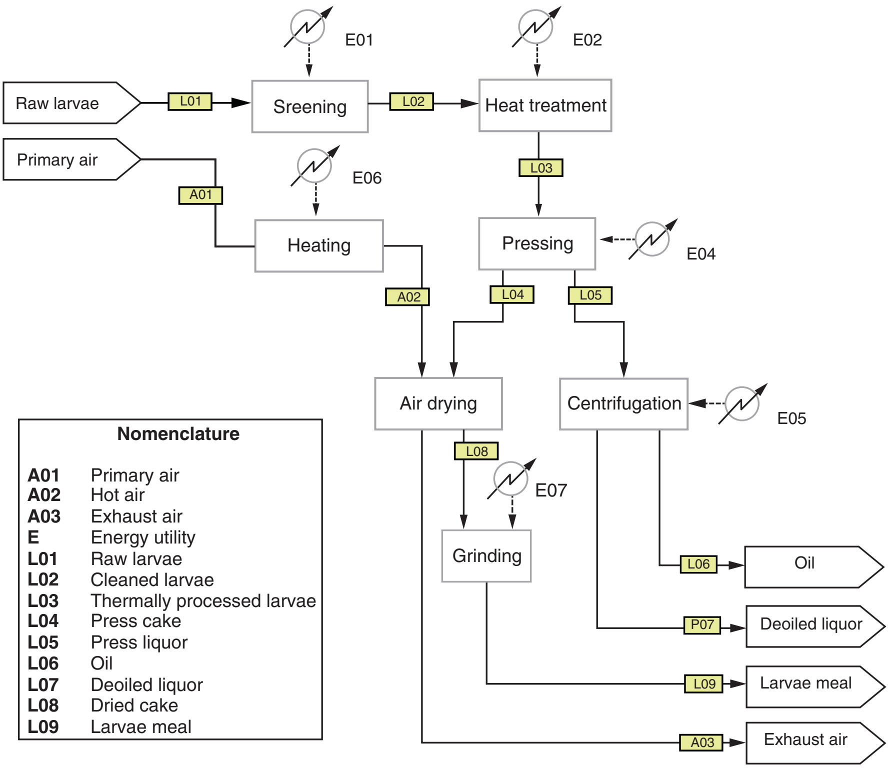
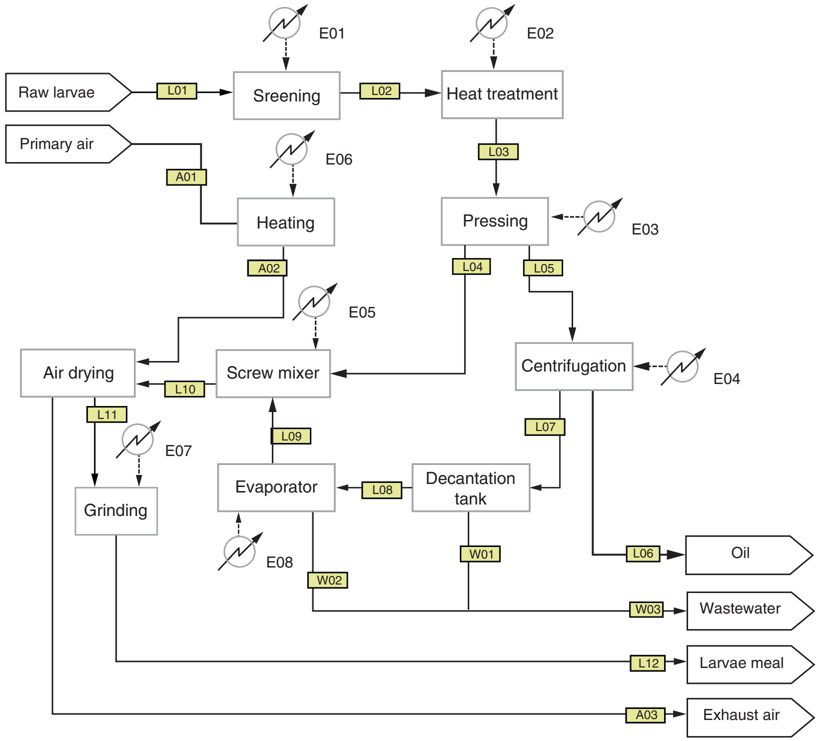


Fig. 13 Fractionation of the whole larvae into oiled, de-oiled liquor and dried meal phases (scenario 2)

waste. Thereafter, the larvae are thermally treated either by direct immersing into hot water (90–95 °C) for 10–15 min or by steam jet impingement (100 °C). The heat treatment is necessary for inactivating protein-degrading enzymes and preserving the biofunctional compound effectiveness. The moisture content of the heat-treated larvae L03 increases slightly. The moisture intake varies between 2 and 3%. The third step consists in drying the larvae with air A02 at a temperature ranging 60–100 °C, down to 5–10% wb of moisture. The dried larvae L04 are then ground to obtain wholemeal flour of larvae L05.

In the second scenario (Fig. 13), the heat-treated larvae L03 are pressed in order to obtain a press cake L04 and a pressing juice L05 (called ‘press liquor’). The press cake includes 60–70% db (dry basis) of the initial proteins. The lipid separation yield is about 50%. The recovering of lipid L06 (called ‘oil’) from the press liquor is performed by centrifugation. Finally, the press cake is dried and then ground to produce a more stable larvae flour L09 as it includes fewer lipid content than the wholemeal. However, the larvae meal includes less protein than the wholemeal because a fraction of proteins remains in the de-oiled liquor L07.

In order to recover the residual proteins, a number of thermomechanical dehydration steps are required. The third scenario (Fig. 14) shows the recovery steps of the



Nomenclature

A01	Primary air	**L02**	Cleaned larvae	**L07**	Deoiled liquor	**L12**	Larvae meal
A02	Hot air	**L03**	Thermally processed larvae	**L08**	Decanted liquor	**W01**	Decanted water
A03	Exhaust air	**L04**	Press cake	**L09**	Concentrate	**W02**	Condensates
E	Energy utility	**L05**	Press liquor	**L10**	Solid mixture	**W03**	Wastewater
L01	Raw larvae	**L06**	Oil	**L11**	Dried solid		

Fig. 14 Fractionation of the whole larvae into oiled and dried meal phases (scenario 3)

residual proteins. Given its high water content (80–90% wb), the de-oiled liquor must first be filtered or decanted. After that, the decanted liquor L08 is concentrated in a single or multiple effects evaporator station, down to 50–55% wb of moisture. The concentrates L09 are then mixed with the press cake to be dried. This scenario allows for production of a protein-rich larvae meal, however, it requires more steps compared to the second scenario.

Mass and energy balances

This subsection inventories macroscopic mass and energy balances of the three scenarios given in the overall flowsheets (Figs. 12, 13 and 14). A number of operating parameters are summarized below:

- 1 kg of raw larvae L01 includes 60% proteins, 25% lipids, and 7% chitins. The remaining fraction (8%) is unspecified and includes glucose, minerals etc.

Table 5 Mass fractions of flux components (scenario 1)

	Flow	Moisture	Protein	Lipid	Chitin	Unspecified
		% wb	Db			
Raw larvae	L01	60.00	0.60	0.25	0.07	0.08
Cleaned larvae	L02	60.00	0.60	0.25	0.07	0.08
Thermally processed larvae	L03	60.47	0.60	0.25	0.07	0.08
Dried larvae	L04/L05	5.00	0.60	0.25	0.07	0.08

Notes: *wb* wet base, *Db* dry base

Table 6 Mass fractions of flux components (scenario 2)

	Flow	Moisture	Protein	Lipid	Chitin	Unspecified
		% wb	db			
Raw larvae	L01	60.00	0.60	0.25	0.07	0.08
Cleaned larvae	L02	60.00	0.60	0.25	0.07	0.08
Thermally processed larvae	L03	60.47	0.60	0.25	0.07	0.08
Press cake	L04	50.00	0.70	0.16	0.08	0.05
Press liquor	L05	76.96	0.25	0.54	0.03	0.17
Oil	L06	0.00	0.00	1.00	0.00	0.00
De-oiled liquor	L07	86.47	0.50	0.10	0.06	0.33
Dried solid	L08/L09	5.00	0.70	0.16	0.08	0.05

Notes: *wb* wet base, *Db* dry base

- The average moisture content of the raw larvae is about 60% wb (1.5 db).
- The separation efficiency of the pressing of proteins and lipids in the press cake are 0.9 and 0.5, respectively.
- The separation efficiency of the lipids in the centrifuge is 0.9.
- The final water content of the larvae meal is set at 5% wb (0.05 db).
- The water intake during the heat treatment is set at 2%.

The composition of the raw larvae is obtained from laboratory analyses. The composition at the output of each process step is obtained from a mass balance calculation.

Stream composition summary is given in Tables 5, 6 and 7. In scenario 1, the composition of the dry matter is homogeneous. Only the moisture content decreases during drying. However, in scenarios 2 and 3, the composition of the dry matter changes due to the pressing step. In scenario 2, the protein fraction increased from 24% wb to 67% wb in raw and meal larvae respectively. In scenario 3, the protein fraction increases from 24% wb to 64% wb. The fraction of proteins in scenario 3 is lower because the larvae meal includes, in addition to proteins, chitins and unspecified compounds. Based on the consumption of various energy utilities (Fig. 15), the energy consumption in scenario 3 is higher than that of scenario 2. Therefore, the interest of recovering all proteins in the larvae flour may be counterbalanced by the energy cost, and by the high investment cost (i.e. evaporators). In all cases, the drying process is the most energy-intensive step. Scenario 2 may be the most appropriate alternative in terms of energy consumption and product quality.

Table 7 Mass fractions of flux components (scenario 3)

	Flow	Moisture	Protein	Lipid	Chitin	Unspecified
		% wb	db			
Raw larvae	L01	60.00	0.60	0.25	0.07	0.08
Cleaned larvae	L02	60.00	0.60	0.25	0.07	0.08
Thermally processed larvae	L03	60.47	0.60	0.25	0.07	0.08
Press cake	L04	50.00	0.73	0.17	0.09	0.01
Press liquor	L05	75.06	0.23	0.47	0.03	0.27
Oil	L06	0.00	0.00	1.00	0.00	0.00
De-oiled liquor	L07	84.02	0.40	0.08	0.05	0.47
Decanted liquor	L08	82.55	0.40	0.08	0.05	0.47
Concentrate	L09	60.00	0.40	0.08	0.05	0.47
Mixture	L10	52.15	0.68	0.15	0.08	0.09
Dried solid	L11/L12	5.00	0.68	0.15	0.08	0.09

Notes: *wb* wet base, *Db* dry base

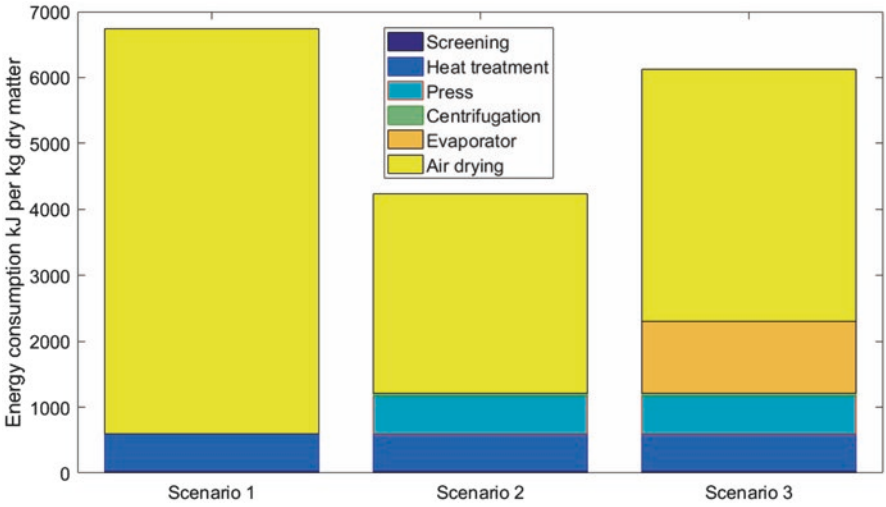


Fig. 15 Comparison of energy consumption in the three scenarios process steps

4.3 Summary of the Middle-Sized Transformation Line

This subsection deals in particular with the description of a medium-scale processing. The annual production is set at about 10,000 tons at 5% moisture of insect meal. Table 8 shows approximate quantities of material flow rate and power consumption of the steps taken into account in each scenario. The obtained flow rates are generally small or medium and vary between 2 and 5 tons per hour. The production of larvae meal at 5% moisture content in each scenario corresponds to about 1660 kg per hour. This production requires processing of a raw larvae flow at 60%

Table 8 Inventory data from simulation (annual production of insect meal of 10,000 tons at 5% moisture, i.e. 1577 kg of dry insect meal per hour)

	Scenario 1		Scenario 2		Scenario 3	
	Material flow rate (kg/h)	Power (kW)	Material flow rate (kg/h)	Power (kW)	Material flow rate (kg/h)	Power (kW)
Screening	3943	14	5100	18	4442	16
Heat treatment	3943	248	5100	321	4442	280
Pressing	–	–	5161	323	4496	281
Centrifugation	–	–	2014	1	1680	1
Drying	3990	2693	3147	1723	3238	1824
Decanting	–	–	–	–	1479	–
Evaporation	–	–	–	–	1348	579

moisture content of about 3943, 5100 and 4442 kg per hour, respectively for scenarios 1, 2 and 3. In scenario 1, the full protein fraction is recovered in the insect meal. In scenarios 2 and 3, the protein yields are 90% and 95% respectively.

The drying process is viewed as the most energy consuming with about 2693, 1723 and 1824 kW, for scenarios respectively 1, 2 and 3. The total electrical power consumed is approximately 14 kW, 342 kW and 298 kW, for scenarios respectively 1, 2 and 3. The total thermal power is approximately 2941 kW, 2044 kW and 2683 kW, for scenarios respectively 1, 2 and 3. At this stage of the study, it is difficult to confirm the most efficient scenario. On the one hand, the final product does not have the same functional properties. On the other side, taking into account investment costs can counterbalance the economic performance of the scenarios.

5 Questions and Challenges

The prospect of rearing farms and insect transformation on an industrial scale for animal feed is on the verge of becoming a global reality due to the increasing demand for sustainable food resources.

Business concerns are already active on the market of products specifically designed for animal nutrition. Many of them are small or medium-scale ventures and independent start-ups, with a strong interest for innovation, focusing on or participating in various R&D projects, such as:

- SUPRO 2, a Dutch project associating a private operator called Proti-Farm with Wageningen University
- BIOCONVAL, a Danish project also involving the same private company, Proti-Farm, along with ICROFS (International Centre for Research in Organic Food Systems)

- AQUAFLY, a Norwegian project associating another private concern called Protix with NIFES (National Institute of Nutrition and Seafood Research)
- DESIRABLE, a French project in which a private company called YNSECT joins up with AgroParisTech.

These companies show a real eagerness for an innovative development of this sector by adapting their skills or setting-up new activities.

However, the large-scale production and use of insect-based products must meet several technical, economic and regulatory challenges.

In Europe, the industrial rearing of insects for animal nutrition is only beginning and is therefore still a relative novelty. If we compare it with the level of knowledge and know-how already accumulated in the conventional rearing of standard species (i.e. bovines, pigs, etc.), a quantum leap is required to catch up.

The problems met are those pertaining to any industrial rearing, but many steps are yet to be optimized, such as the selection of edible insects and of their growth stage, their reproduction cycle, their breeding conditions, their feeding (affordable and healthy feed, supplementation with micronutrients adapted to each species, etc.), as well as the steady and regular supply of biomass for their nutrition, designing the facilities, automation or mechanisation, 'good manufacturing conduct'.

As for average-sized farms, the main problems encountered are logistical. The transportation of large larvae towards transformation units requires specific studies, as it is currently based on an apparatus which does not exist yet (in our research described in Sect. 1).

Regarding large-scale units (farms producing 2000 tons), the main problem is space occupancy, as it runs counter to the imperative of operating within a limited timeframe. As soon as you increase space occupancy, you increase line lengths and necessary work time. For instance, a given operation may demand 72 h to be carried out when, due to insect physiology, you may have only 24 h at hand. Prior to the setting-up of integrated systems it is crucial to design rearing apparatuses that are specifically adapted.

Nevertheless, these questions are beginning to be progressively addressed by several research teams in Europe and a number of recent studies have shown that the goal of obtaining a positive environmental balance is within reach.

The recommendations put forward during the expert consultation on insects as food and feed at FAO in January 2012 and based on studies conducted by experts, stress the following points: the constitution of collections of species and lineages; health, safety and environmental issues; strategic problems met by industrial insect farmers (FAO/WUR, 2012). The European Food Safety Authority (EFSA) for its part has stressed the importance of production methods, the substrate used to feed the insects, the insect life cycle stage during which they are harvested, the insect species, for the purpose of evaluating possible biological and chemical hazards (EFSA, 2015).

The contenders holding the greatest potential in terms of large-scale production, due to their productivity and breeding efficiency, are mainly: the black soldier fly larvae (*Hermetia illucens*), the common housefly larvae (*Musca domestica*) and the mealworm larvae (*T. molitor*).

Concerning transformation, as we have described it above in Sect. 3, insects must undergo a series of treatments in order to make them fit for industrial use. Of utmost importance is the need to master the quality and supply of the raw material (selection, development stage, insect diet), as well as operating conditions necessary to obtain end-products showing the desired features (protein flours and isolates; foodstuffs or ingredients, etc.). Mass-produced insects could possibly either be processed as whole insects, or fractionated into various components such as protein, oil or chitin. The food industry happens to be already using similar techniques in this fractioning operation, in the soya and fish-farming industries for instance. Thus, the preparation of protein concentrates or isolates often involves the extraction of the oil from the raw material, allowing for the generation of a de-fatted product. Moreover, one must also consider the need for automation, control and regularity of production so as to supply the market steadily. All of that remains a challenge for the development of this industry.

The technical data of transformation scenarios, with their mass and energy balances, gathered through experimental studies, may reflect a certain industrial reality, but they might be subject to significant variations depending on the context. It would be necessary to supplement them with a study of transformation costs, related to equipment, amortisation, labour, financial charges, the need to finance the exploitation cycle. Labour costs can be worked out on the basis of a three shifts-a-day activity for a period of 250 days (50 weeks of five days) or 330 days. It is important to note that uncertainty regarding labour costs is significant as the evaluation of the workforce needed can vary greatly depending on the level of automation.

However, once these hurdles have been overcome, the question of the cost of insect protein remains critical. As of today, insect production as an alternative source of proteins is still too expensive in comparison with conventional sources, particularly soya meal. Various sources point out to varying prices differentials. For example Veldkamp et al. (2012) evaluates the price of mealworm at 31.7 per kg, to be compared with a price of 0.62 per kg for soybean meal. Whereas Peyraud (2016) for his part has shown a cost differential of two to ten. For its part, the Netherlands-based Proti-Farm private concern came out in 2016 with a trading price of 15 per kg for mealworm meal, to be compared with a price of 0.37 per kg for soymeal.

In order to decrease this cost, one would have to consider the valorisation of protein by-products (chitin, lipids, etc.) thanks to the setting-up of a biorefinery. This entomo-refinery would associate a breeding apparatus that would valorise organic matter, initially without much added value, with a sustainable transformation of insects into a whole range of products or compounds with an interesting marketable value, such as bio-fuels for energy production (Azagoh et al. 2015).

6 Conclusion

Satisfying the growing demand for proteins, notably for the purpose of feeding animals, and toning down the impact of animal husbandry on the environment, while at the same responding to public demand for product quality, are major challenges for international organisations, private operators and agri-food researchers.

Among several possible additional sources of proteins, the insect solution seems to be relevant and credible as a complementary option alongside other conventional ones (fish and soy).

The development of an insect industry must necessarily take into account the availability of the resource (insects and insect feed), rearing methods, as well as transformation technologies. But one must also keep in mind the potential and accessibility of markets targeted, considering the competitive offer.

This chapter briefly documented only one part of the results of the DESIRABLE project. Its specific contribution involves designing livestock management and processing facilities on an industrial scale, while dealing with the articulations within the production/processing system. Studies raised research questions in animal selection, agronomy, economy and technology. It is expected that the French projects will contribute to a better understanding of *T. molitor* industrial rearing and processing systems. This project aims at demonstrating that the setting-up of huge insect farms faces many obstacles. Another part of the project is devoted to social and environmental consequences, and calls into question the sustainability of such gigantic systems. Sustainability of future facilities will stem from a better understanding of insect biology, appropriate logistics and affordable feed ingredients, in order to achieve both quality and cost objectives.

The research carried out during the DESIRABLE project contributes to a better understanding and to designing new solutions for small farms as well, provided they are run so as to ensure operational efficiency.

Acknowledgments This work received support by the French National Research Agency (ANR-12-ALID-0001) through its DESIRABLE project (Designing an insect biorefinery to contribute to a more sustainable agro-food industry).

References

Azagoh C, Hubert A, Mezdour S (2015) DESigning the insect bio refinery to contribute to a more sustainABLE agro- food industry. J Insects Food Feed 1(2):159–168

Berk Z(1992) Technology of production of edible flours and protein products from soybeans. In: Soymilk and related product. Chapter 5, FAO Agricultural services Bulletin, No 97, ISSN 0022–3166

Eilenberg J, Vlak JM, Cappellozza S, Jensen AB (2015) Diseases in insects produced for food and feed. J Insects Food Feed 1(2):87–102. https://doi.org/10.3920/JIFF2014.0022

European Food Safety Authority Scientific Committee (EFSA) (2015) Scientific opinion on a risk profile related to production and consumption of insects as food and feed. EFSA J 13:4257

FAO (Food & Agriculture Organization) (2014) Insectes comestibles Perspectives pour la sécurité alimentaire et l ' alimentation animale. FAO Forestry Paper.Editeur : FAO, 2014–207

FAO/WUR (2012) Expert consultation meeting: assessing the potential of insects as food and feed in assuring food security. Vantomme P, Mertens E, van Huis A, Klunder H (eds) Summary report, 23–25 Jan 2012, Rome

Farina L, Demey F, Hardouin J (1991) Production de termites pour l'aviculture villageoise au Togo. Tropicultura 9(4):181–187

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327:812–818

Iroko AF (1982) Le rôle des termitièresdansl'histoire des peuples de la RépubliquePopulaire du Bénin des origines a nos jours. Bulletin de l'I.F.A.N, 44: 50–75

Morales-Ramos JA, Rojas MG, Kay S, Shapiro-Ilan DI, Tedders WL (2012) Impact of adult weight, density, and age on reproduction of Tenebrio molitor (Coleoptera: Tenebrionidae). J Entomol Sci 47(October):208–220. Retrieved from <Go to ISI>://WOS:000306775300002

Newton L, Sheppard C, Watson DW, Burtle G (2005) Using the black soldier fly, Hermetiaillucens, as a value-added tool for the management of swine manure. North Carolina State University, North Carolina

Perez Galvez R (2009) Le compactage, une solution pour un meilleur management des bioressources marines. Application aux rejets et co-produits de poisson. Thèse Ifremer et Université de Nantes. 311p

Peyraud JL (2016) L'élevagecontribue à la production durable des protéines.Viandes&Produits Carnés 32-4-1

Ramos-Elorduy J, González EA, Hernández AR, Pino JM (2002) Use of Tenebrio molitor (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. J Econ Entomol 95(1):214–220. https://doi.org/10.1603/0022-0493-95.1.214

Sheppard DC, Newton GL, Thompson SA, Savage S (1994) A value added manure management system using the black soldier fly. Bioresour Technol 50(3):275–279

Van Broekhoven S, Oonincx DG, van Huis A, van Loon JJ (2015) Growth performance and feed conversion efficiency of three edible mealworm species (Coleoptera: Tenebrionidae) on diets composed of organic by-products. J Insect Physiol 73:1–10. https://doi.org/10.1016/j.jinsphys.2014.12.005

Veldkamp T, van Duinkerken G, van Huis A, Lakemond CMM, Ottevanger E, Bosch G, van Boekel MAJ (2012) Insects as a sustainable feed ingredient in pig and poultry diets – a feasibility study. Wageningen UR Livestock Research, (report 63(October)), 62

Importance of Insects for Use as Animal Feed in Low-Income Countries

Syrine Chaalala, Achille Leplat, and Harinder Makkar

Abstract Insects provide an alternative sustainable source of protein to the growing population, as well as to the animals in the low-income world. The depletion of resources linked with the increased demand for animal products due to growing population and fast-growing economies of the low-income countries make insects a sustainable alternative to fish and soybean meal for the livestock and aquaculture sectors. The insect meal market has a great potential for innovation. Growth of alternative protein sources is poised to accelerate, potentially claiming up to a third of the protein market by 2054, profoundly affecting agriculture, food technology, and end products. Insect meal, made largely from larvae, is rich in high quality protein (45–68% dry matter basis), has a good amino profile and high digestibility. This new resource could substitute soybean meal and fishmeal in animal and fish diets. Such livestock farming has the potential to reduce importation dependency in low-income countries and boost the local and participatory economy. Small scale farms can strongly contribute to the improvement of small farmers' livelihood by not only generating an additional source of income, but also alleviating the dependency on currently marketed animal feed, whose prices have quintupled in the past 15 years. With a low initial investment required in equipment, space and water-resource, smallholder farmers can contribute to the development of their local economies and sustainable development of their regions, aligning with the United Nations Sustainable Development Goals (SDGs).

S. Chaalala (✉) · A. Leplat
nextProtein, Paris, France
e-mail: s.chaalala@nextprotein.co

H. Makkar
Food and Agriculture Organization of the United Nations, Rome, RM, Italy

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_18

1 Context

Sustainably meeting global food supply is a major challenge of the twenty-first century. By 2050, world population is expected to increase to 9.6 billion from the current level of around 7.3 billion. As a result of increased population, urbanization and economic growth in low-income countries, coupled with changing diets (i.e. higher consumption of animal source foods, fruits and vegetables) and countering malnutrition and hunger-alleviating efforts on-going in low-income countries, food demand is projected to rise by at least 70% globally, and almost 100% in the low-income world (FAO 2011; HLPE 2016).

Wasteful consumption patterns in the developed world and lack of post-harvesting infrastructure in low-income countries are diminishing the world's natural resources. Depletion of fossil hydrocarbons is causing an increased demand for biofuels and creating not only competing land-use priorities but also requiring increased overall agricultural production in addition to an extensive use of grains for animal feed (almost 33% globally), exacerbating the situation.

Farmers worldwide will need to increase crop production, either by increasing the amount of agricultural land to grow crops or by enhancing productivity on existing agricultural lands with the use of fertilizer, irrigation and other innovative and smart technologies. Limiting factors to expanding agricultural lands are numerous: increasing population, urbanization, and climate change, among others. A sustainable option is to increase productivity – to produce more from less.

Currently, agriculture uses 70% of the Earth's fresh water, and reserves are dwindling resulting in a predicted 40% shortfall by 2030 (WWAP, 2015). The projected increase in livestock production can lead to huge pressure on water availability and quality, eutrophication and acidification, land degradation and deforestation, reduced air quality, increased greenhouse gas emissions and biodiversity loss (Mekonnen and Hoekstra 2012).

This chapter discusses implementation and importance of insect production in the small-scale operation because of their high relevance for low-income countries.

1.1 Insects as a Beneficial Resource

Because of growing demand for animal source foods and declining availability of agricultural land and other natural resources, there is an urgent need to find alternative protein sources with low environmental and economic costs. It is also worth noting that the global fish reserves are dwindling, which are the sources of fishmeal. The use of insects in animal feed is a potential path to improve the sustainability of animal diets and meet the growing global demand for livestock products (Verbeke et al. 2015).

As for both human food and animal feed, edible insects can alleviate waste disposal problems by being grown on organic by-products. This requires additional research on the impacts of such processes on both human and animal health. A study by the European Food Safety Authority (EFSA 2015) assessed "potential biological and chemical hazards, as well as allergenicity and environmental hazards, associated with farmed insects used in food and feed taking into account the entire value chain, from farming to the final product". The main findings of the study are that "the specific production methods, the substrate used, the stage of harvest, the insect species, as well as the methods used for further processing will all have impact on the possible presence of biological and chemical contaminants in insect food and feed products".

Risks to human and animal health depend on how the insects are reared and processed. In addition, the total environmental impact of insect rearing is still being discussed (van Huis et al. 2015), and depends on several parameters including the type of rearing systems, the substrates used and products obtained (Muys et al. 2014; Roffeis et al. 2015). However, there is a consensus that insects can be grown on low value by-products or organic waste from agriculture and food industries, producing valuable high quality protein with a nutritive value comparable to soybean meal or fishmeal. Insects are also a good source for amino acids, fatty acids and micronutrients (Makkar et al. 2014; Rumpold and Schlüter 2013a, b). Insect production systems bring back valuable ingredients from organic waste materials derived from agriculture, food industries and other sectors into the food chain.

1.2 Insects as Animal Feed

In many countries in Africa and Asia, poultry and fish production are among the fastest growing agri-businesses. With 60–70% of animal production costs going into feed, poor availability and low quality of feed, combined with the high cost of soybeans and cereals used as feed ingredients, are severely constraining growth in the sector. The introduction of insect farming can significantly contribute to the exponentially growing demand for sufficient, affordable and sustainable proteins.

With a short reproductive cycle, an interesting nutritional profile and low initial investment required for rearing, insects are an ideal bioconversion tool that can deliver a high value added protein-rich material from 'wastes' (Gahukar 2016).

Although there are many insect species that can be used as animal feed, *Hermetia illucens*, commonly known as black soldier fly (BSF); *Musca Domestica*, commonly known as the housefly; and *Tenebrio Molitor*, commonly known as Mealworm, are currently the most widespread insects reared for animal feed on a small to large industrial scale. Furthermore, many research centres are currently looking into several insect species to be reared and integrated into animal feed. The *International Centre of Insect Physiology and Ecology* has developed multiple programmes, in collaboration with established research centres, to research and further develop the use of insects as a source of protein in feed in Eastern Africa.

2 Small-Scale Insect Farming: An Overview

The size of an insect operating system depends essentially on its ability to process the amount of substrate needed to transform the larvae into proteins, which is directly correlated with the workforce required for its management.

Larvae, once the fattening step is carried out, and after harvesting, are separated from their development substrate through sieving. This batch of fresh larvae may be used as a feed source in poultry farms or small aquaculture activities, generating income. As a second source of income, the farmer may produce insect meal to sell to the feed processing industry.

BSF and housefly maggots can be reared and grown on a large array of substrates. They are able to, through a bioconversion process, transform food waste into a valuable product, rich in protein and fat, able to provide an alternative to soybean meal and fishmeal in animal feed. It also allows for the valorisation of organic waste, creating an additional potential income generating market.

Privileging proximity to poultry and pig farms in order to obtain supplies of slurry and other animal waste product as a substrate for larvae growth is a must. It should also take account of the traditional methods used in livestock farming in low-income countries making automation and highly industrialized techniques not conceivable. The prospect of insect-rearing implementation in such a context inevitably should take these factors into consideration.

2.1 Circular Economy and New Agri-Business Sector

Implementation of a small insect-rearing farming system would increase availability of good quality feed locally and enable smallholders to integrate the livestock and fish rearing systems and increase their productivity, in addition to contributing to the environmental protection of the area of implementation. A small-scale insect-rearing farm has significant advantages for a low-income country. Its requirement for a small production area for satisfactory yields gives it high potential to develop a new agri-business sector. In addition, it can easily be incorporated into a local breeding system and does not require a large distribution network.

Insect rearing activities may be an asset in organizations and village communities in low-income countries. Indeed, adding such an activity makes it possible to provide a solution in the management of livestock wastes, effluents and other organic wastes. A study has shown that the BSF is an effective tool to reduce swine and poultry farming effluents up to 56% in term of mass and 40–55% in nutrients (Newton et al. 2005). Rearing of the BSF is complementary to other on-going rearing operations and not expected to present an intrusive aspect that can hinder local economic activity. The development of small-scale systems can lead to the organization of cooperatives and to the sustainable development of communities and villages (van Huis 2013).

A small-scale system reduces the investment costs for the farmer and makes it easy to organize the production system into a production unit adapted to the stages of larvae development. Moreover, the infrastructure can easily be built with low-cost materials that are accessible locally to most. The breeding parameters of a small system are in most cases generally aligned to environmental conditions and therefore require little energy in Africa and Asia for instance.

Small-scale systems require little labour, which facilitates its implementation. The work schedule is not extremely restrictive and can be combined with other activities. A small insect colony allows flexibility in the management, better control of production monitoring and facilitates standardization of insect batches. Less intensive breeding reduces risks of external pressures, minimizes risks of consanguinity and genetic fatigue.

2.2 The Challenges of Rearing Operations

An important challenge of a rearing operation that cannot be taken for granted is consanguinity, genetic fatigue and dependency on climatic variations. An intensive breeding operation can rapidly be subjected to a diminished production due to an immune deficiency and high stress level in the larval population (Erens et al. 2012). There have only been preliminary studies establishing correlation between these two factors and several insect-rearing operations have been faced with such a challenge and have become aware of the importance of the introduction of a new strain/batch into the population. It can lead to visible morphological defects in the adult stage, which have a negative impact on production. Preserving the genetic variability of the insect population is important for long term sustainability.

A disadvantage of a small system in a low-income country is the inability to have adequate equipment to control temperature and light intensity factors. Tomberlin and Sheppard (2002) showed that temperature and light intensity significantly influence ovulation and reproduction. The variation of natural light intensity is a real risk in the standardization system. Also, a lack of knowledge about insect rearing particularly about the importance of the quality of the manure and rearing conditions lead to a low production capacity. According to Ekesi and Mohamed (2011), feed and rearing conditions influence growth, survival fecundity, fertility and mating ability of the insect. Capacity building of smallholder farmers by local technical organizations can mitigate some of these challenges. Preserving the genetic variability of the insect colony is important for long-term success. Insect farming is therefore a matter of careful rearing, diligent monitoring of quality control parameters and periodic strain restoration or replacement (GREEiNSECT 2016).

2.3 Important Factors to Take into Account in Determining Feasibility

Understanding the context of low-income countries is essential in the implementation of an insect rearing farm. Although a small investment is required initially, there is no room for erroneous spending. It is important to identify the available resources prior to setting up a rearing system. Priority lies with the selection of the location of the farm in order to ensure sufficient, safe and regular availability and short distance travel of organic waste necessary for the development of the insects. An analysis of the local context is vital in determining feasibility and reducing costs as much as possible. Low agricultural productivity and reduced food waste may limit the breeder's input for larval development and the successful implementation of the activity. Alternative sources of substrate must be identified at the early stages of development in order to provide variability and minimize dependency on one source.

2.4 Decision Making Framework Before the Establishment of a Small-Scale System

Small scale insect farming can provide an alternative source of income to rural populations in low-income countries and reduce dependency on imported products, which are becoming increasingly inaccessible to smallholder farmers. Established according to the standards currently being developed by the industry's leaders and organizations for insect farming (e.g., International Platform of Insects for Food and Feed (IPIFF) and ASEAN Food and Feed Insects Association (AFFIA), and in order to be sustainable and contribute to economic growth, small-scale farms have to integrate in the specific economic environment to be profitable. For instance, an insect farm connected to a poultry farm may have a positive synergetic effect on both productions.

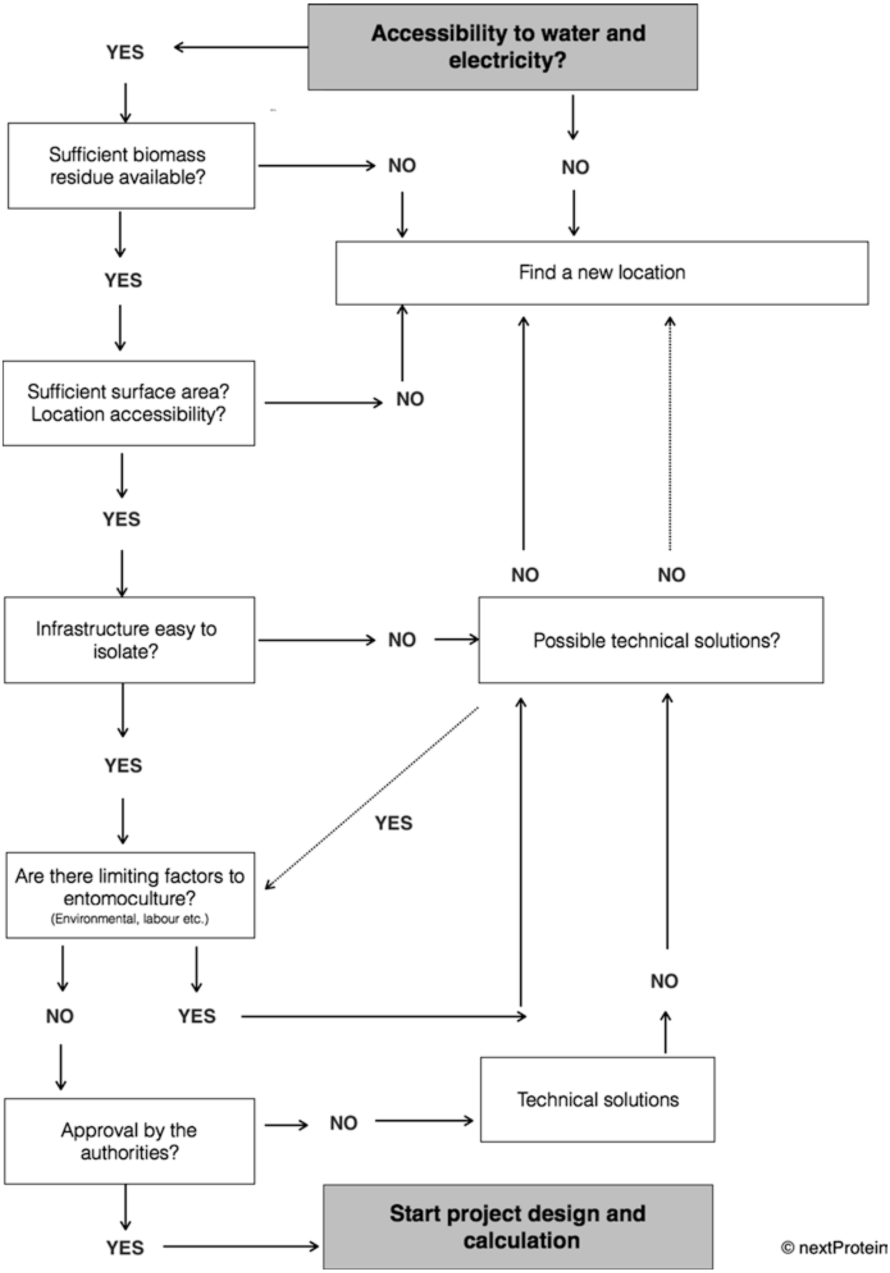
This decision-making framework can be used to determine feasibility of the project prior to the initial physical and financial investment. Some conditions are critical in ensuring the successful implementation of the farming system.

2.5 Choosing the Insect

Among the most promising species for industrial feed production are BSF, common housefly larvae, silkworms and yellow mealworms. Grasshoppers and termites are also viable, but to a lesser extent. To date, these species are the most studied and account for the majority of the literature (van Huis et al. 2013).

A study carried out on waste management showed that BSF and housefly have a degradation capacity of 56% and 75% in terms of mass, respectively (Barnard et al.

Table 1 Decision making framework



1998; Newton et al. 2005). In addition, both insects have the ability to grow on a wide range of decaying organic matter (Van Huis et al. 2013; Makkar et al. 2014). In this regard, in addition to being an alternative source of protein, they can be used as a means to manage livestock manure and fight organic pollution in developing countries.

The BSF's bioconversion process of degrading the nutrients present in animal waste reduces potential pollution by 50–60% and reduces the development of dangerous diseases for humans and livestock (Newton et al. 2005). Furthermore, the BSF is not perceived as a pest because adults are not attracted to human habitats and food, unlike domestic flies (Newton et al. 2005). In comparison, the housefly has a shorter breeding cycle, 6–10 days (Makkar et al. 2014), but presents risks to pathogen transmission.

The use of the insect meal from housefly or BSF seems to have relatively similar effects in terms of production performance. Both insect meals may be considered to be alternatives to soybean meal and fishmeal in their nutritional value and show significant performance in chicken and laying hens (Makkar et al. 2014). Nevertheless, the content of insect meal inclusion in the animal diet plays an important role in their growth performance. With regard to pig farming for instance, it seems that the housefly is a better choice than the BSF because the latter may present a risk of deficiency in essential amino acid (Makkar et al. 2014). Both insects present a potential for rearing in low-income countries regardless of the financial constraints.

3 Main Risks of Farming Systems

3.1 Airflow

Four major factors come into play and may pose risk in both small and large-scale systems: resourcing of appropriate substrates for insect rearing, rearing material, availability of human resources and airflow (Erens et al. 2012). To ensure good growth rate and productivity, good air quality is essential. The airflow system's role is critical to allow enough inlet air to maintain acceptable humidity, a steady temperature, remove waste gases, dust and odours. The incoming air should be free of pathogens and dust.

3.2 Contamination

Insect rearing farms are also prone to external contamination, in particular fungal and bacteriological (Sikorowski and Lawrence 1994). Such contaminations could destroy the entire production and would force farmers to reinvest in a new batch of insects to restart the production. This may not be a viable option for farmers in developing countries due to their limited investment capacity; therefore, precautions have to be taken and biosecurity measures established.

Contamination influences growth and limits production. In fact, microbes affect the symbiotic microbial communities of insects (Engel and Moran 2013) essential for maintaining the insect health. For instance, a microbial contaminant can modify the pH of the substrate and directly impact the insect productivity (Erens et al. 2012). A critical point is in the management of inputs, from reception to distribution. A primary process of waste treatment without a pasteurization phase is certainly a risk in the sustainability of the system but can be managed by following best practices such as appropriate resourcing of substrates and their storage in a dry area (risk of disease transmission and maggot contamination can be lowered through the reduction of moisture in the substrate).

Rearing parameters, particularly density of insects, are a critical point to avoid a microorganism contamination. A too high density in rearing is the first factor that could lead to disease development (Erens et al. 2012). A balance in the population density has to be determined and maintained in order to decrease contamination risks. Wilson et al. (2002) showed that an adapted density of population allows for better resistance to fungi and other external contamination. Neutral contamination area and organisation of the units according to rearing phases are essential to reduce the risk of transmission in case of contamination. The system must be designed to isolate the infected area and carry out an emergency protocol. Being an innovative field, not much information is currently available on such contaminations and decontamination protocols, but research is on-going. A *best practices to insect rearing*'s biosecurity guide is currently being developed by the members of the International Platform of Insects for Food and Feed (IPIFF).

3.3 Organic Inputs: Traceability

Moreover, a reliable supply of clean feed to use as larval development substrate is necessary. Presence of toxic elements can be a major risk for the production and limit distribution to food industry because of health regulation. Studies have shown that BSF have a high bioaccumulation capacity, compared to mealworms, for lead and cadmium from organic waste (Van et al. 2016).

Besides contamination risks, the limited capacity to control rearing parameters for a farmer in low income countries may result in difficulties to meet production goals and to cope with threats like pathogens contamination, mortality, low growth, low fertility, among others. Lack of data collection expertise may prove difficult for adapting the system in case of negative impacts on the production. At minimum, a farmer should control and record two main parameters (growth and fertility) to keep the insect rearing under control.

3.4 Investment

The project Ento-Prise financed by the Department for International Development (DFID) in Ghana in 2016 gives a rough idea of the investment required to set up a small-scale system. The system was organized into separate buildings for the broodstock, the larvae production and the storage. The operating space of 220 m^2 makes it possible to manage a daily supply of 330 kg of waste per day. In this case, resourcing of substrates (fruits and vegetables) is carried out from the nearest market. The larvae development is done in containers (15 bays) of 2 m^2, and three wooden cages are sufficient for the production. The construction of the units is valued at 6000 US$ and the ancillary pieces of equipment (cages, ovens etc.) cost around 1250 US$. The administrative cost for obtaining a license was 300 US$. Fixed costs are valued at 7550 US$ and operational costs at 192 US$ per month including water and electricity, contingency, substrate resourcing, and workforce. The GVA (Gross Value Added) gives a first idea of the income generated through breeding, per year. Self-consumption is not taken into account here since the whole production is destined for commercialization. The raw products are here limited to the sale of dry larvae and fertilizer. Intermediate consumption refers to the purchase of organic waste, replacement equipment (plastic gloves, etc.) and consumption of water and electricity. For the year 2016, the GVA amounted to approximately 1907 US$. As for the net value added, it amounts to approximately 1400 US$ per year. It is also interesting to look at GVA/h because it takes into account the time required to maintain the insect rearing system. For a small operating system, one hour per day is sufficient for the preparation of the feed mixture and its rationing, one hour for the collection of eggs and distribution in the incubators. On this basis, we estimate the working time required at 92 h per month, i.e. 1104 h per year. The valuation of the work is therefore 1.73 US$ per hours per day. It may be noted that the World Bank estimated the average annual salary of 129 US$ in Ghana in 2012. Such exploitation would allow multiplying yearly income three-fold (Table 2).

4 Making Small Scale Insect Rearing Farm More Efficient

4.1 Rearing Features and Growth Parameters for BSF and the Housefly

The housefly has a life cycle similar to the BSF with respect to eggs, larvae or maggot, pupal and adult stages. The housefly requires a warm environment for its development. Each female lays an average of 500–600 eggs under natural conditions and with controlled temperature and humidity parameters, may lay over 2000 eggs. The eggs require a temperature of between 25 and 30 °C and a high substrate moisture of the order of 60–75%. It takes 8–12 h of incubation for the first larvae to appear. Larvae under similar conditions require 5 days to reach the pupation stage and then

Table 2 Gross Value Added (GVA) – Net Value Added (NVA) (per year)

	Gross income		
Description	*Quantity (kg)*	*Unit price (US$)*	*Total price (US$)*
Fertilizer	27,000	0.077	2079
Dry Larvae	2268	0.94	2132
Subtotal	**4211**		
	Expenses		
Description	*Quantity (kg)*	*Unit price (US$)*	*Total price (US$)*
Feed (organic matter)	118,800	0.008	960
Small lab equipment	–	–	480
Water and electricity	–	–	480
Miscellaneous	–	–	384
Subtotal	**2304**		
GVA	**1907**		
Depreciation	*Total purchase price (US$)*	*Product life time*	*Cost/year (US$)*
Building	6000	20	300
Wooden cage	90	5	18
Oven	160	7	22.8
Bays/containers/trays	1000	15	66.67
License	300	3	100
Total	**507**		
NVA	**1399**		

4–5 days for final maturation. The total cycle is between 6 and 10 days, a variation is possible depending on the stability of the parameters of growth i.e. temperature and humidity and nutrient component of low-income substrates (Arong et al. 2011). Adults can live between 15 and 25 days depending on the availability of food especially sugar. The breeding conditions are fairly stable for the different stages of development (Feedipedia 2016). The adult fly tolerates a low temperature close to 25 °C, but Sheppard et al. (2002) showed that the oviposition was more effective in a temperature range of 27.5–37.5 °C.

The rearing of the BSF requires strict management of the parameters. Its rearing should be organized in different phases adapted to its development cycle. The adult fly has a lifespan ranging from 8 to 12 days or more depending on its sex. Indeed the BSF does not need to feed; it draws from the reserves gathered during its larval stage. A temperature between 25 and 38 °C and relative humidity above 50% is recommended (Barry 2004). After emergence, flies take 2 days to start breeding and nearly 70% lay eggs 2 days later (Tomberlin and Sheppard 2002). The fattening of the larvae, which could vary from 14 days to 4 months (Hardouin and Mahoux 2003), depending on the quality of the ration/diet, temperature and moisture of the substrate. The ideal temperature for the fattening phase is between 27 and 33 °C (Harnden and Tomberlin 2016). This stage of growth is broken down into two phases, incubation and fattening. Since the incubation phase is the most important, a temperature of 29–30 °C and a relative humidity of more than 55% (Holmes et al. 2012) should be respected in order to minimize the number of days in the egg state, maximize the early stages of growth and approach a 15-day production cycle. The fattening phase requires about 8 days depending on the quality of the food. The pupation stage is 14 days (Makkar et al. 2014), which is a function of temperature. Moreover, at the same temperature, female larvae tend to have longer larval and pupal development duration (Tomberlin et al. 2009).

4.2 Breeding Management and Sexual Cycle Control

The breeding parameters must allow the farmer to control the insect population. Larval growth should be monitored as an indicator of the efficacy of the system, which, to a large extent, depends on the quality of inputs, particularly food substrate. By calculating the sustainable growth rate, the breeder will be able to establish a database allowing interpretation of any disturbance. This will enable to establish reference data for the breeding system. The management of the reproduction is carried out by a posteriori analysis of the results obtained at the end of the productive cycle (15 days for BSF) and through a daily management of the batches. The analysis of the results makes it possible to observe and assess the batch results in relation to the old batch, to identify priority actions (increase ration amount, change the food mix etc.), identify the probable causes of the problems in order to suggest improvements and establish relationships between results and batch management. The daily management of batches is carried out by a fertility planning process, which should highlight the critical areas of reproduction and the dates of reintroduction of the pupae to maintain the density and stability of the colony. This way of management should allow the farmer to move towards an objective standardization and better insect rearing.

4.3 Insects for Waste Treatment?

Low-income countries are faced with a major challenge. The demand for waste treatment is increasing as a result of fast growing populations. Inadequate waste treatment results in appalling conditions in villages and towns and increases diseases. An entomological system could be a way for processing and recycling waste.

The larvae have high growth potential over a large range of substrates (Banks et al. 2014). BSF develops optimally on livestock manure with 40–60% moisture content (Fatchurochim et al. 1989). The substrate moisture level is a main control parameter since it directly influences the bioconversion performance of the larvae and thus the duration of the production system (Makkar and Ankers 2014). Indeed, if the substrate is too moist, the energy required for nutritional activity will be compromised by the mobility of larvae in search of food (Fatchurochim et al. 1989; Makkar and Ankers 2014). Apart from substrate moisture, its availability will affect the life cycle of both growth and reproductive performance in the adult stage (Myers et al. 2008). According to studies conducted by Diener et al. (2009), the best compromise between the reduction of the effective substrate and the biomass produced (dried larvae) is a daily provision of substrate mix (diet) of 3–5 kg/m^2 of market waste (fruits and vegetables) and 6.5 kg/m^2 of human faeces. Poultry manure has a composition that varies greatly according to the type of ration fed to poultry, the poultry species and its stage of development as well as characteristics such as its moisture, ammonia content, pH of the manure, among others (El Boushy 1991). Dry manure is not a good substrate since half of the proteins are not nitrogen proteins, which go off to the air on drying, thereby decreasing its nutrients (El Boushy 1991). It would seem that a varied rationing is better than a single component in the diet.

It would then be necessary to vary, depending on local availability, among poultry, pig and human wastes. A study on the development of BSF larvae on human faeces by Banks et al. (2014) showed that rationing of 100 mg/larva/day is more efficient in its conversion to larvae biomass than the swine or chicken manure, with a feed conversion ratio of 2.0–3.3. Substrate protein content is not the main factor for influencing the nutritional composition of insect meal. Nevertheless, quality of substrates directly impact ash and ether extract (EE) contents (Spranghers et al. 2016). The variety of the substrate can be considered as a means of improving the fattening. It is possible that the change of type of ration, by bringing new nutritional elements, may increase its palatability for larvae.

4.4 Scaling-Up

Different ways can be envisaged to increase the productivity of the system. Insect rearing companies practice several methods: one of the first methods to increase the efficiency of insect rearing system is vertical production. It allows for the optimization of the production area. Furthermore, it offers another advantage for the layout of the rearing area because it becomes easier to adapt and modify the units according to needs and production capacity.

Horizontal operations are also used. They are ground-level operations that require more land space, but have their advantages. They allow to increase insect density and to set up a self-collection method of the larvae during the pre-pupation, reducing the overall workforce.

The performance of the two approaches mentioned above depends on the density of larvae per m^2. Parra Paz et al. (2015) showed that bioconversion of larvae was mainly affected by its density. Moreover, in order to generate as much biomass as possible, a system as a whole can be maximized at a density of 5 larvae/cm^2 provided that a daily rationing of 95 mg/larvae/day (on dry matter basis) is available.

5 Consumer Acceptance: The Cultural Dimension

The potential of insects, both for feed and food, has been widely acknowledged in the 2013 'Edible insects' report published by the Food and Agriculture Organization of the United Nations (van Huis et al. 2013). Just as recently as on December 13th 2016, EU Member States formally approved the European Commission's proposal aiming at authorising the use of insect proteins in aqua feed. Insect proteins are expected to be authorised for use in fish feed in Europe as of 1st July 2017. However, while insect use as feed for livestock, is widely accepted in many parts of Asia, Latin America and Africa, there is still cultural resistance in other parts of the world, especially in the Western world. But perceptions are changing. According to PROteINSECT's Consensus Business Case Report (Smith and Barnes, 2015). Approximately 73% of people who responded would be willing to eat fish, chicken or pork from animals fed on a diet containing insect protein. Only 6.5% said that they would not. In a survey-based study done in Flanders, Belgium, attitudes towards the idea of using insects in animal feed was generally acceptable, most notably for fish and poultry feed. Two-thirds of the respondents were willing to accept the use of insects in animal feed. The foods obtained from animals fed on insect-based feed were widely accepted (Verbeke et al. 2015).

While studies have shown that the adoption of insects or insect-based foods by consumers cannot be taken for granted (Schösler et al. 2011; Verbeke et al. 2015; Tan et al. 2015), there is general acceptance of their use in the diets of poultry, pigs, ruminants and aqua species. It is pertinent to mention that in a survey-based study to prioritize elements of sustainable animal diets, in the environment dimension of the sustainability, highest priority was given to the use of food and agricultural wastes as animal feed (Makkar et al. 2014) which is consistent with the use of vegetables, fruits and agricultural wastes as substrates for producing insect meal for use in the livestock sector.

Animal welfare by the insect rearing industry, especially for consumer acceptance in Europe and North America may also need to be considered in the future. Insects are considered as livestock and should therefore be slaughtered in a humane way. There is a consensus that insects have nociceptors, or pain receptors, and can therefore react to stimuli, although it is unclear whether insects can experience pain in the same way as mammals do. According to some experts, freezing the insects should be practiced.

In countries where consuming insects is a traditional part of the food culture, for example in Asia, South America and Africa in particular, the economic potential of rearing insects for human and animal consumption largely remains untapped. If it has been realised, it is a small-scale house-hold operation.

6 Conclusion

The insect rearing supports the realisation of *Sustainable Development Goals* (SDG) of the United Nations. Insect rearing, by offering reduced land competition between food and feed crops, provides an opportunity to increase food security (SDG 2). Improved waste management and a move towards a circular economy (SDG 9) have positive effects on the environment (SDG 13) and give impetus to sustainable agriculture (SDG 2). In addition, they improve human health and well-being by reducing occurrence of diseases and also by increasing availability of animal source foods especially in middle- and low income countries (SDG 3). Industrial insect farming could become a novel economic sector, promoting economic growth and generating employment (SDG 8) and would also promote sustainable industrialization and foster innovation (SDG 9).

One of the major current challenges includes clear legislations. There are many insect rearing-substrates, insect species, insect-consuming countries, and thereby requirement for different legal and regulatory frameworks. In some regions, laws concerning the safety of the substrate on which insects are reared are not as restraining as they are in the European Union. It is believed that the restrictive European Union regulations pose a major barrier for the investment in this industry and for its expansion worldwide. In addition the insect rearing industry is in its infancy and there are many research issues (Makkar et al. 2014) that need to be addressed. The safety of the insect meal used on different substrates is of prime importance. For a successful expansion of the insect industry, a strong partnership between public and private industry is needed. The industry, government including regulatory authorities, and research institutions need to work in tandem to address the challenges.

References

Arong G, Imandeh G, Utsu AA, Sha KK (2011) The influence of food type on larval growth in Musca domestica and Lucilia sericata (Diptera) in Calabar, Nigeria. World J Sci Technol 1(4):73–77

Banks IJ, Gibson WT, Cameron M (2014) Growth rates of black soldier fly larvae fed on fresh human faces and their implication for improving sanitation. Tropical Med Int Health 19(1):14–22

Barnard DR, Harms RH, Sloan DR (1998) Biodegradation of poultry manure by house fly (Diptera: Muscidae). Environ Entomol 27(3):600–605. https://doi.org/10.1093/ee/27.3.600

Barry T (2004) Evaluation of the economic, social, and biological feasibility of bioconverting food wastes with the black soldier fly (Hermetia illucens). Ph.D. Dissertation, University of Texas, August 2004, 176 pp

Diener S, Zurbrügg C, Tockner K (2009) Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. Waste Manag Res 27:603–610. https://doi.org/10.1177/0734242X09103838

EFSA Scientific Committee (2015) Risk profile related to production and consumption of insects as food and feed. EFSA J 13(10):4257

Ekesi S, Mohamed SA (2011) Mass rearing and quality control parameters for tephritid fruit flies of economic importance in Africa. In: Akyar I (ed) Wide spectra of quality control. InTech. https://doi.org/10.5772/21330

El Boushy AR (1991) House fly pupae as poultry manure converters for animal feed: a review. Bioresour Technol 38(1):45–49. https://doi.org/10.1016/0960-8524(91)90220-E

Engel P, Moran NA (2013) The gut microbiota of insects – diversity in structure and function. FEMS Microbiol Rev 37(5):699–735. https://doi.org/10.1111/1574-6976.12025

Erens J, Es van S, Haverkort F, Kapsomenou E, Luijben A (2012) Large-scale insect rearing in relation to animal welfare. Master's Thesis, Wageningen UR

FAO (2011) World livestock 2011- livestock in food security. FAO, Rome

Fatchurochim S, Geden CJ, Axtell RC (1989) Filth fly (Diptera) oviposition and larval development in poultry manure of various moisture levels. J Entomol Sci 24(2):224–231

Feedipedia (2016) Animal Feed Resources Information System - INRA CIRAD AFZ and FAO, Rome. Available from www.feedipedia.org

Gahukar RT (2016) Edible insects farming: efficiency and impact on family livelihood, food security, and environment compared with livestock and crops. In: Dossey AT, Morales-Ramos JA, Rojas MG (eds) Insects as sustainable food ingredients: production, processing and food applications. Academic Press, New York, pp 85–111. https://doi.org/10.1016/B978-0-12-802856-8.00004-1

GREEiNSECT (2016) Technical brief #1: Insects as food and feed in Kenya – past, current, and future perspectives. International Conference on Legislation and Policy on the Use of Insect as Food and Feed in East Africa

Hardouin J, Mahoux G (2003) Zootechnie d'insectes – Elevage et utilisation au bénéfice de l'homme et de certains animaux. Bureau pour l'Echange et la Distribution de l'Information sur le Mini-élevage (BEDIM), Belgium

Harnden LM, Tomberlin JK (2016) Effects of temperature and diet on black soldier fly, Hermetia illucens (L.) (Diptera: Stratiomyidae), development. Forensic Sci Int 266:109–116. https://doi.org/10.1016/j.forsciint.2016.05.007

HLPE (2016) Sustainable agricultural development for food security and nutrition: what roles for livestock? A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome, July 2016

Holmes LA, Vanlaerhoven SL, Tomberlin JK (2012) Relative humidity effects on the life history of Hermetia illucens (Diptera : Stratiomyidae). Environ Entomol 41(4):971–978

Makkar HPS, Ankers P (2014) Towards sustainable animal diets: a survey-based study. Anim Feed Sci Technol 198:309–322. https://doi.org/10.1016/j.anifeedsci.2014.09.018

Makkar HPS, Tran G, Heuzé V, Ankers P (2014) State-of-the-art on use of insects as animal feed. Anim Feed Sci Technol 197:1–33

Mekonnen MM, Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. Ecosystems 15(3):401–415

Myers HM, Tomberlin JK, Lambert BD, Kattes D (2008) Development of black soldier fly (Diptera: Stratiomyidae) larvae fed dairy manure. Environ Entomol 37(1):11–15

Muys, B., Roffeis, M., Pastor, B., Gobbi, P., Martínez-Sánchez, A., Rojo, S., Zhu, F., Mathijs, E., Achten, W.A., 2014. Generic life cycle assessment of proteins from insects. Insects to Feed The World, 1st 23 International Conference 14–17 May 2014, Wageningen (Ede), The Netherlands. FAO, Wageningen 24 Unversity, p. 107

Newton GL, Sheppard DC, Burtle G, Watson DW, Dove R (2005) Using the black Soldier Fly, Hermetia illucens, as a Value-Added Tool for The Management of Swine Manure. Report for Mike Williams Director of the Animal and Poultry Waste Management Center, North Carolina State University, Raleigh

Parra Paz AS, Carrejo NS, Gómez Rodríguez CH (2015) Effects of larval density and feeding rates on the bioconversion of vegetable waste using black soldier fly larvae Hermetia illucens. Waste Biomass Valoris 6:1059–1065. https://doi.org/10.1007/s12649-015-9418-8

Rumpold BA, Schlüter OK (2013a) Potential and challenges of insects as an innovative source for food and feed production. Innovative Food Sci Emerg Technol 17:1–11

Rumpold BA, Schlüter OK (2013b) Nutritional composition and safety aspects of edible insects. Molecular Nutrition and. Food Res 57(3):802–823
Schösler H, de Boer J, Boersema JJ (2011) Can we cut out the meat of the dish? constructing consumer-oriented pathways towards meat substitution. Appetite 58(1):39–47
Sheppard DC, Tomberlin JK, Joyce JA, Kiser BC, Sumner SM (2002) Rearing methods for the black Soldier Fly (Diptera: Stratiomyidae). J Med Entomol 39(4):695–698
Sikorowski PP, Lawrence AM (1994) Microbial contamination and insect rearing. Am Entomol 40(4):240–253. https://doi.org/10.1093/ae/40.4.240
Smith R, and Barnes E, (2015) PROteINSECT Consensus Business Case Report: 'Determining the contribution that insects can make to addressing the protein deficit in Europe, Minerva Health & Care Communications Ltd
Spranghers T, Ottoboni M, Klootwijk C, Ovyn A, Deboosere S, De Meulenaer B, Michiels J, Eeckhout M, De Clercq P, De Smet S (2016) Nutritional composition of black soldier fly (Hermetia illucens) prepupae reared on different organic waste substrates. J Sci Food Agric. https://doi.org/10.1002/jsfa.8081
Tan HSG, Fischer ARH, Tinchanc P, Stiegera M, Steenbekkersa LPA, van Trijp HCM (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89
Tomberlin JK, Sheppard CD (2002) Factors influencing mating and oviposition of black soldier flies (Diptera: Stratiomyidae) in a colony. J Entomol Sci 37(4):345–352
Tomberlin JK, Adler PH, Myers HM (2009) Development of the black soldier fly (Diptera: Stratiomyidae) in relation to temperature. Environ Entomol 38(3):930–934. https://doi.org/10.1603/022.038.0347
van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583
van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects – future prospects for food and feed security. FAO Forestry Paper 171
van Huis A, Dicke M, van Loon JJA (2015) Insects to feed the world. J Insects Food Feed 1:3–5
Van der Fels-Klerx HJ, Camenzuli L, van der Lee MK, Oonincx DGAB (2016) Uptake of cadmium, lead and arsenic by tenebrio molitor and Hermetia illucens from contaminated substrates. PLoS One 11(11):e0166186. https://doi.org/10.1371/journal.pone.0166186
Verbeke W, Spranghers T, De Clercq P, De Smet S, Sas B, Eeckhout M (2015) Insects in animal feed: acceptance and its determinants among farmers, agriculture sector stakeholders and citizens. Anim Feed Sci Technol 204:72–87. https://doi.org/10.1016/j.anifeedsci.2015.04.001
Wilson K, Thomas MB, Blanford S, Doggett M, Simpson SJ, Moore SL (2002) Coping with crowds: density-dependent disease resistance in desert locusts. Proc Natl Acad Sci 99:5471–5475
WWAP (United Nations World Water Assessment Programme) (2015) The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris, UNESCO

Sustainable Mealworm Production for Feed and Food

Lars-Henrik Heckmann, Jonas Lembcke Andersen, Natasja Gianotten, Margje Calis, Christian Holst Fischer, and Hans Calis

Abstract Sustainable production broadly covers three main pillars: the environmental, economic and social pillars. Much emphasis has been put on the environmental sustainability of insect production, highlighting the great potential of this new type of production as compared to conventional livestock production regarding its reduced impact on the environment and the climate. This chapter will describe some of the efforts that have been conducted and are on-going in recent R&D collaborations on making mealworm production more economically sustainable; focusing on the utilization of low-cost by-products in composite diets designed for mealworms. Other areas of importance for cost-effective production such as automation will also be presented briefly.

1 Introduction

Currently, only a handful of insect species qualify for large-scale production, because their biological requirements are 'easy' to stimulate or are known to a degree that enables commercial insect producers to supply currently relevant market volumes. Among these insects are; the lesser (*Alphitobius diaperinus)*, common (*Tenebrio molitor*) and giant mealworms (*Zophobas morio*). Still, the majority of mealworm producers, in Europe and globally, are relying on expensive and inefficient manual labour, unfit for industrial level production. Furthermore, the applied feed is, as such, not nutritionally designed for production of mealworms and the yield is therefore not fully optimized, as is the case with traditional production animals like fish, poultry and pigs. Hence, production of mealworms is not yet fully economically competitive with other animal protein sources for feed and food (INBIOM 2015–2016). Yet, there are ongoing developments amongst mealworm

L.-H. Heckmann (✉) · J. L. Andersen · C. H. Fischer
Danish Technological Institute, Life Science, Aarhus, Denmark
e-mail: lhlh@teknologisk.dk; jlan@teknologisk.dk; chfi@teknologisk.dk

N. Gianotten · M. Calis · H. Calis
Proti-Farm R&D, Ermelo, The Netherlands
e-mail: ngianotten@protifarm.com; mcalis@protifarm.com; hcalis@protifarm.com

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_19

producers that aim to make future production more cost-effective. Some of these challenges include for instance: (i) development of feed that meets species- and life stage-specific nutritional needs leading to maximal reproduction or biomass yield/turnover; (ii) optimization of feeding frequency and feed load in the production trays to facilitate the best feed conversion efficiency; (iii) optimization of larval density to enable optimum biological temperature in the production trays and hence maximum output during the biomass production cycle; (iv) increasing production output by increasing the number (stacking height) of trays per square meter in the production facilities; and (v) reducing risk of diseases (e.g. Eilenberg et al. 2015), which will inevitably increase with increased production area and density in the trays. In this chapter, the main focus will be on the nutritional needs of the lesser and common mealworm to ensure optimal biomass yield. This will be discussed in regards to research efforts from recent and ongoing projects (SUSMEAL 2015–2018; INBIOM 2015–2016) building on top of current industry experience.

2 Moving Towards Sustainability

Sustainability is often defined as covering three main pillars: the environmental, economic and social pillars. Generally, much emphasis has been put on the environmental sustainability of insect production, highlighting the great potential of this new type of production as compared to conventional livestock production regarding its reduced impact on the environment (e.g. water consumption) and climate (Oonincx and de Boer 2012). When comparing insects to conventional livestock, resource-efficient use of feed is also a parameter that should to be promoted regarding environmental sustainability. Currently, the feed conversion efficiency of mealworms is comparable to poultry and approximately two to five times higher than pigs and cattle, respectively (van Broekhoven et al. 2015; van Huis 2013). Moreover, the produced animal-based food is likewise used more resource-efficiently with insects, as the whole animal is edible; for comparison, only 40–55% of the produced biomass of poultry, pigs and cattle are applied directly as food (van Huis et al. 2013). Yet, the environmental sustainability of insect production goes beyond water consumption, CO_2 emissions and resource-efficiency (e.g. van Huis et al. 2013). For instance, certain ‘less quantifiable’ parameters such as biodiversity and animal welfare are likely to be considered to a higher extent than in conventional production systems. However, there is a lack of literature to make a relevant comparison, although insect welfare has recently received attention (e.g. Gjerris et al. 2016).

Apart from environmental sustainability, there is also the aspect of economic sustainability. One of the major hurdles to overcome in order to improve the economic sustainability and competitiveness of insect production is the current production system. As of now, most large scale as well as small scale productions are taking place in boxes in racks, upheld in large part by personnel and relatively simple automation solutions. Decreasing the amount of manual labour via a more automated system, such as an all-in-one modular solution, could decrease the number of man-hours significantly, decreasing the price of the final product. This is in regards to both manual handling (feeding, harvesting, etc.) as well as health inspection of the production animals. The feasibility of such modular and automatic systems are currently being investigated in different EU based R&D projects (SUSMEAL 2015–2018; inVALUABLE 2017–2019); and improvements are likewise made to early adaptions of existing automation systems. Another part of economic sustainability is maximizing output/yield, optimizing product quality and minimizing losses during the entire production process. A major effort in this area is the development of composite and nutritionally-balanced feed for insects, which, over the coming years, is expected to increase the production yield significantly and thus improve the resource-efficiency of insect production even further. In the following section, we will focus on feed development and outline some of the recent research that has been conducted and is currently ongoing.

3 Designing Composite Feed for Mealworm Production

As mentioned in the previous section, mealworms have a very high feed conversion efficiency. This is to a large extent due to the fact that insects are poikilothermic; and hence use no energy on maintaining a fixed internal temperature like other vertebrate livestock (excluding fish). Like any other organism, mealworms have unique biological requirements specific to both the respective species as well as different life stages. In that respect, it is key to obtain detailed biological knowledge of, for example, mealworm nutrition to generate an economically desirable (protein-rich) biomass while simultaneously ensuring a high feed conversion efficiency (van Broekhoven et al. 2015; Rho and Lee 2014; Rho and Lee 2016). Other areas of biological importance to insect production include reproduction and overall physiological optima regarding temperature, relative humidity and population density. In the following, focus will be on the nutritional needs of the larval stage of lesser and common mealworm. Until now, animal feeds already applied in agro-systems, particularly for poultry, are being utilized for insect production including mealworms and crickets. Research efforts in development of composite feed for mealworms are, however, on-going. Many of these efforts focus on using low-cost by-products and side-streams to support the environmental sustainable perspective that the insect industry is aiming for, as part of an overall branding and economic strategy.

One of the largest producers of lesser mealworms in Europe is Proti-Farm (formerly Kreca), which is based in The Netherlands. At present, a large-scale production facility is under construction with an expected output of several thousand tons of larval biomass per year once running at full capacity. This process is running consecutively with an EU based R&D project SUSMEAL (2015–2018), partnering Proti-Farm, Danish Technological Institute and Hannemann Engineering. SUSMEAL is investigating how to produce lesser mealworms cost-effectively at large-scale, and the main objectives of the project are: (i) development of low-cost nutritious feed for lesser mealworm, with consistently high protein content; and (ii)

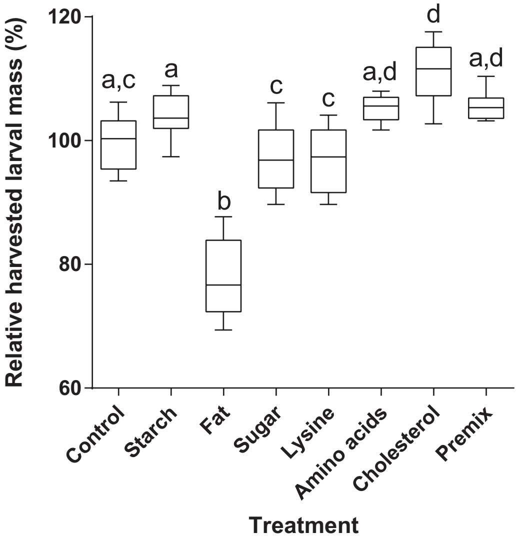


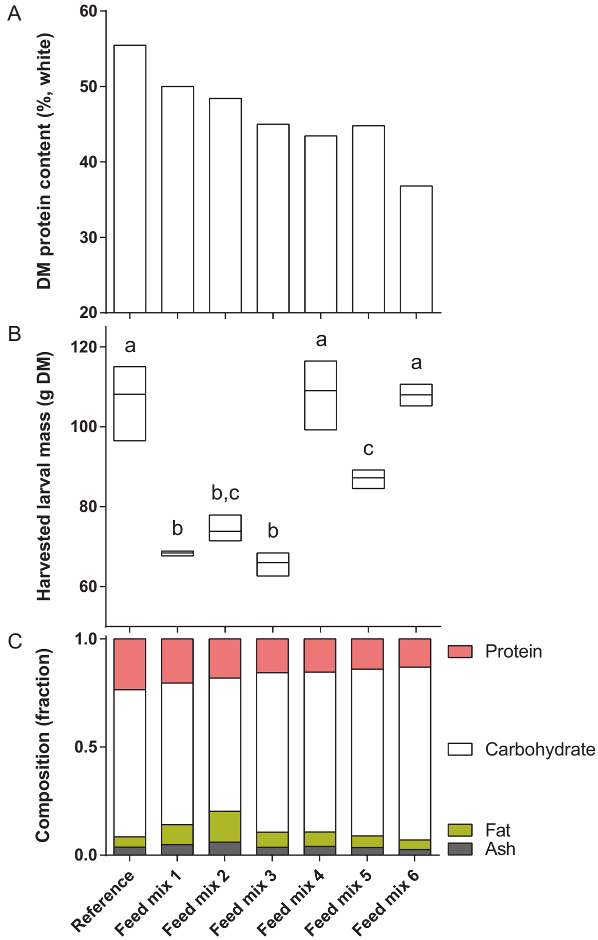
Fig. 1 Harvested larval mass of lesser mealworm relative to a base substrate (Control) from a 4-week production trial. The experimental feed treatments are composed of the base substrate with addition of different nutrients. Different letters (*a-d*) indicate significant differences in the harvested biomass from the experimental feeds ($p < 0.05$, $N = 10$, 1-Way ANOVA with Tukey's multiple comparison tests)

integration of automation in production regarding handling, and monitoring of lesser mealworm health and maturity.

Both overall composition of the feed and the individual nutrients are of great importance for growth of lesser mealworm. Several studies are being or have been conducted under SUSMEAL to identify which factors are of the highest importance in relation to feed conversion efficiency and biomass yield. From both SUSMEAL (2015–2018) and other relevant projects (e.g. INBIOM 2015–2016, see below), it is clear that in order to ensure high productivity of the lesser mealworm, high quality feed is needed with appropriate macro- and micro-nutrient levels. Similarly, it is key to ensure that vegetable-based raw materials or residues from the food and feed industry are applied in order to secure overall food safety in compliance with EU feed legislation.

Some of the results from the SUSMEAL project are shown in Fig. 1. The data is collected from a series of experiments looking at different additions of nutrients to a base substrate. The study highlights a number of interesting things regarding the overall nutritional requirements of lesser mealworms. For instance, the addition of fat seems to have a very negative effect on the growth rate, lowering biomass yield to less than 80% compared to the control. However, an increase in yield of around 10% higher than the control is achieved when adding a specific type of fat, cholesterol. This is a good example of how nutritional optimization in feed development requires specificity at micronutrient level, since addition of lipids (i.e. fatty acids or cholesterol) can have very different outcomes. Another example is the addition of a mix of amino acids and the addition of lysine, specifically. Here the addition of lysine alone does not increase yield as compared to the control, whereas the addition of a range of amino acids result in significantly higher growth and less variation in mass across different experimental production boxes. Addition of premixes,

Fig. 2 (**a**) Percentage amount of protein (dry mass) after 4 weeks. The amount of fed protein is based on the protein content in dry biomass (N = 1, pooled sample). (**b**) Total harvested dry mass of common mealworm after 4 weeks, presented as average (line) and min to max (box). For protein and harvested mass, letters (*a-c*) indicate significant differences (P < 0.05, N = 3, one-way ANOVA with Tukey's multiple comparisons) between the different feed mixes. (**c**) The fraction of ash, fat, carbohydrates and protein content in the feed mixes



made for traditional farm animals also show promising results. This indicates that even minor changes in available micronutrients can be fine-tuned to a high degree to optimize growth and maximize the larval mass at harvest. Future optimization of the composition and level of minerals and vitamins in the feed will likely have major impact on mealworm growth performance.

Biomass yield is obviously of high importance from an economic perspective, which also includes focus on especially protein content of the produced mealworms. The protein level of mealworms (and other insects) can vary considerably comprising between 40–60% of the dry mass. Hence, there is great focus on ensuring the protein content by optimizing the mealworm feed. Figure 2 shows data from an experiment conducted during a Danish R&D project (INBIOM 2015–2016) aimed at developing low cost feed for common mealworm based on by-products from the food industry. The study was conducted with 2-week-old larvae reared for 4 weeks on six experimental feed treatments that were all compared to a reference feed applied in hobby-rearing of mealworms obtained from CJ WildBird Foods Ltd. (The Rea, United Kingdom). The six feed mixes were composed of flour from different grains, peas, rice and milled bread. Looking at the protein content of the feeds (Fig. 2c), it is highest in the reference feed (24%) and decreases across the six feed mixes with approx. 20% in feed mix 1 and 13% in feed mix 6. Yet, when looking at the harvested mass (Fig. 2b) as well as the protein content (Fig. 2a), there is an indication that increased protein may lead to higher protein content of the larvae. The protein content of the final product is highest when larvae are fed on the reference feed. However, when looking at the yield of larvae, those fed on feed mix 4 and 6 are not significantly different from the reference feed, indicating that these relatively simple and comparatively cheap mixes (the reference feed is priced at approx. 5.7 EUR/kg) have great potential as a base feed for common mealworm.

A result worth highlighting is that the overall composition of feed mix 3 and 4 are nearly identical (approx. 15% protein, 73% carbohydrates and 7% fat), but the biomass yields are significantly different (see Fig. 2b). The main difference between feed mix 3 and 4 is that there were two extra flour components present in feed mix 4; underscoring that diversity in the feed may add value as it will more likely ensure a more nutritionally-balanced diet by increasing availability of certain nutrients of importance to the common mealworm. This is in line with the results from SUSMEAL (2015–2018) presented above on the influence of premix on the growth of lesser mealworm. Another important observation was the difference in output between feed mix 3 and 5. These feed mixes were both composed of three components, with pea and rice flour comprising equal levels in the mixes but with the main component (constituting two thirds of the feed) differing between the feeds (milled white bread in feed mix 3 vs. rye flour in feed mix 5). Yet, the substitution of the main, carbohydrate-rich, component resulted in a significantly higher biomass yield in mealworms fed on feed mix 5 (Fig. 2b); and although the protein content of feed mix 5 was somewhat lower than in feed mix 3, there was no difference in the protein content of the final product between the two treatments.

A number of previous studies on mealworms show that biomass gain and body composition, and hence nutritional quality, can be altered by diet (Davis and Sosulski 1974; Davis 1975; Ramos-Elorduy et al. 2002; van Broekhoven et al. 2015). Vertebrates are not able to synthesize (adequate amounts of) the essential amino acid needed to fulfill their nutritional requirements, hence why these nutrients need to be supplied through the diet. This is also the case for mealworms (and likely most/all insects), as shown by Davis (1975). van Broekhoven et al. (2015) conducted a comparative study with the lesser, common and giant mealworm fed on a range of commercial and experimental diets. Their results revealed differences in larval development time, survival and growth within the respective species when fed on diets with different protein and starch content. Likewise, there was a considerable difference between species (in relative terms) in the impact on the above-mentioned end points, when fed diets of the same composition. Dietary protein content had a minor effect on mealworm protein content, whereas larval fat content and fatty acid composition varied over a wider range. The authors conclude that diets high in yeast-derived protein appear favourable with respect to reduced larval development time, reduced mortality and increased weight gain. Furthermore, they highlight that studies spanning several insect generations should be performed to determine the effect of diet composition on adult fecundity (van Broekhoven et al. 2015). Davis and Sosulski (1974) claim that yeast supplies essential growth factors, which is absent in other protein sources (e.g. cereals or casein). For instance, they show that common mealworms raised on a diet of 90% wheat and 10% brewer's yeast gained twice as much weight as larvae fed on diets containing only wheat or casein (Davis and Sosulski 1974).

Insects and other invertebrates are known to apply different feeding (foraging) strategies to sustain their nutritional needs. Herbivores and omnivores adjust their feed selection behaviour to regulate the intake of multiple nutrients, whereas carnivores optimize their prey capture rate rather than selecting prey according to nutrient composition (Mayntz et al. 2005). Mayntz et al. (2005) tested whether terrestrial invertebrate predators could forage selectively for nutrients when experiencing nutritional imbalances. The nutritional state was manipulated by feeding a diet with either a high or low ratio of protein to lipid. Overall, the results of Mayntz et al. (2005) show that the intake of the test diets was dependent on the nutrient composition of the previous diet. Selective feeding strategies are expected, also, to be relevant for herbivores and omnivores kept under artificial conditions. Hence, designing nutritionally balanced feed is a priority for industrial insect production, to support optimal growth of the particular species; yet, literature is very scarce regarding foraging strategies for those insects that are currently considered as farmed animals.

4 Conclusion

Currently, insect production in general, including mealworms, is in a developmental phase. However, the insect industry is within reach of being able to support sustainable large-scale production from both an environmental and economic perspective within a very near future. The results and previous findings presented in this chapter on development of feed for mealworms has shown that the composition of feed components is of high importance during the larval phase - both in regards of obtaining high biomass yield as well as ensuring desirable levels of major nutrients such as protein and fat. Over the coming years, further development of feeds designed for different instars will likely get much more attention; just like optimized diets for adults will be prioritized as there is great potential to boost reproductive performance, as has been shown in other terrestrial invertebrates (e.g. Heckmann et al. 2007).

Acknowledgments We gratefully acknowledge the financial support for the SUSMEAL project from the Eurostars program with co-funding from Innovation Fund Denmark (IFD), Netherlands Enterprise Agency (RVO) and the EU Commission; and for the INBIOM project from the Danish Agency for Science and Higher Education under the Innovation Network for Biomass (INBIOM). Finally, we thank the reviewers for their valuable comments on the manuscript.

References

Davis GRF, Sosulski WF (1974) Nutritional quality of oilseed protein isolates as determined with larvae of yellow mealworm, *Tenebrio molitor*. J Nutr 104:1172–1177

Davis GRF (1975) Essential dietary amino acids for growth of larvae of the yellow mealworm, *Tenebrio molitor* L. J Nutr 105:1071–1075

Eilenberg J, Vlak JM, Nielsen-LeRoux C, Cappellozza S, Jensen AB (2015) Diseases in insects produced for food and feed. J Insect Food Feed 1:87–102

Gjerris M, Gamborg C, Röcklinsberg H (2016) Ethical aspects of insect production for food and feed. J Insect Food Feed 2:101–110

Heckmann LH, Ruf A, Nienstedt KM, Krogh PH (2007) Reproductive performance of the generalist predator *Hypoaspis aculeifer* (Acari: Gamasida) when foraging on different invertebrate prey. Appl Soil Ecol 36:130–135

INBIOM (2015–2016) Bio-resources for insect production of protein feed. R&D project funded by the Danish Agency for Science and Higher Education under INBIOM (Innovation Network for Biomass). http://www.inbiom.dk/en/projects/inbiom-projects/mealworms-for-poultry

inVALUABLE (2017–2019) Insect Value Chain in a Circular Bioeconomy. R&D project funded by Innovation Fund Denmark. http://www.inVALUABLE.dk

Mayntz D, Raubenheimer D, Salomon M, Toft S, Simpson SJ (2005) Nutrient-specific foraging in invertebrate predators. Science 307:111–113

Oonincx DGAB, de Boer IJM (2012) Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS One 7:e51145

Ramos-Elorduy J, González EA, Hernández AR, Pino JM (2002) Use of *Tenebrio molitor* (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens. J Econ Entomol 95:214–220

Rho MS, Lee KP (2014) Geometric analysis of nutrient balancing in the mealworm beetle, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae). J Insect Physiol 71:37–45

Rho MS, Lee KP (2016) Balanced intake of protein and carbohydrate maximizes lifetime reproductive success in the mealworm beetle, *Tenebrio molitor* (Coleoptera: Tenebrionidae). J Insect Physiol 91-92:93–99

SUSMEAL (2015–2018) Sustainable Mealworm Production for Feed and Food. R&D project funded under Eurostars by Innovation Fund Denmark, Netherlands Enterprise Agency (RVO) and the European Commission. https://www.dti.dk/projects/project-sustainable-mealworm-production-for-feed-and-food/38305?cms.query=SUSMEAL

van Broekhoven S, Oonincx DGAB, van Huis A, van Loon JJA (2015) Growth performance and feed conversion efficiency of three edible mealworm species (Coleoptera: Tenebrionidae) on diets composed of organic by-products. J Insect Physiol 73:1–10

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

van Huis A, van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects. Future prospects for food and feed security. Food and Agriculture Organization of the United Nations (FAO). Report no. 171. http://www.fao.org/docrep/018/i3253e/i3253e.pdf

Part VII
Consumer Preferences and Acceptability

What Governs Selection and Acceptance of Edible Insect Species?

Sampat Ghosh, Chuleui Jung, and V. Benno Meyer-Rochow

Abstract Entomophagous habits have undoubtedly accompanied the evolution of humankind from its beginnings. With few exceptions, insects are generally non-toxic, nutritious, abundant and easy to collect. About 2000 species of insects are known to be consumed by different ethnic groups. We explored on what basis insect species might be selected as desirable by human consumers and why in many parts of the world eating insects has become obsolete and even turned into a matter of disgust. Traditions obviously play a role and superstition and taboos will have been major factors. However, climatic and ecological characteristics that influence the locally available food insect spectrum and looks, taste, and feel of an insect are further features that come into play. Not to be neglected either are economic considerations, e.g. the time and cost involved in harvesting, purchasing and preparing food insects, be it by drying, cooking, frying, spicing them up with rare or expensive ingredients, etc. Finally, motivation can be a powerful regulator too and whether or not to ingest an insect can depend on whether the act of consumption occurs out of curiosity or a nutritional need, as a special treat or part of a ritual, treatment of a disorder or directive. In this contribution, we examine the various reasons, e.g. based on tradition, nutrition, ecology and economy, for selection, acceptance or rejection of certain species of insects in different regions and cultures.

S. Ghosh
Agriculture Science and Technology Research Institute, Andong National University, Andong, Republic of Korea

C. Jung
Department of Plant Medicine, Andong National University, Andong, Republic of Korea

Agriculture Science and Technology Research Institute, Andong National University, Andong, Republic of Korea

V. B. Meyer-Rochow (✉)
Research Institute of Luminous Organisms, Tokyo, Japan

Department of Genetics and Physiology, Oulu University, Oulu, Finland

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_20

1 Introduction

From a scientific point of view, food can be defined as a substance that provides nutrition in order to maintain life and growth for any life form. To facilitate our understanding of food utilization within the complex structures of food webs, consumers of food, i.e. animals, are assigned on the basis of their preferred foods to different categories like herbivores, carnivores, omnivores, detritivores, etc. Often the introduction of sub-groups like, to list but a few, frugivores (fruit eaters), fungivores (feeding on fungus), insectivores (feeding on insects), piscivores (fish eaters), etc. is deemed necessary and the use of the suffix "–phagy" as in xylophagy (feeding primarily on wood), oophagy (feeding on eggs), saprophagy (living on decayed organic matter), coprophagy (feeding on faeces or dung), necrophagy (feeding on dead or decaying animal flesh), and of course entomophagy (consuming insects) is equally common.

Humans, *Homo sapiens,* are generally considered to be omnivores, i.e. unspecialized feeders, being able to make use of almost any food category available to them, but having gone through a variety of dietetic shifts during their evolutionary history (Fig. 1). And yet, a closer inspection of human food practices worldwide reveals enormous differences in food preferences and food rejections (Meyer-Rochow 2009), observations which had earlier led Rozin (1984) to state that "the best predictor of the food preference of a particular person would be information about the person's ethnic group".

If what is perfectly acceptable to some is causing outright revulsion in others (rats would be one example: Meyer-Rochow et al. 2015; insects another: Evans et al. 2015; Tan et al. 2015), how can we possibly define what "human food" is? Obviously a vast array of factors influences food choice in human societies (Rozin 2007a) and to shed some light on the reasons that govern the food habits in different human societies and even sections of the population within a community, a holistic approach is required. Observations pertaining to studies in fields as diverse as ethnology, anthropology, psychology, ecology, physiology, genetics, economy, climatology, as well as several more need to be considered.

According to the report on the State of Food Insecurity in the world in 2015 by FAO, 795 million people worldwide are undernourished (FAO 2015a). One estimate showed that during the period of 2012–2014, the global food deficit was 67.6 billion kcal/day, an average of 84 kcal/day/undernourished person (FAO 2014a). In the year 2050, the world's population is expected to be 9 billion. The search is on for alternative sustainable food sources to feed the world's increasing human population in future years and the FAO (2014b) calculated that a global food production increase by 70% was needed in order "to feed the world in 2050". As a consequence of the rapid population growth, increasingly more land has been converted to agricultural uses, some of which like raising ruminant livestock, now having come under considerable criticism. In general, animal proteins are of higher nutritional value than plant proteins, because animal proteins contain larger amounts of essential amino acids needed for human development

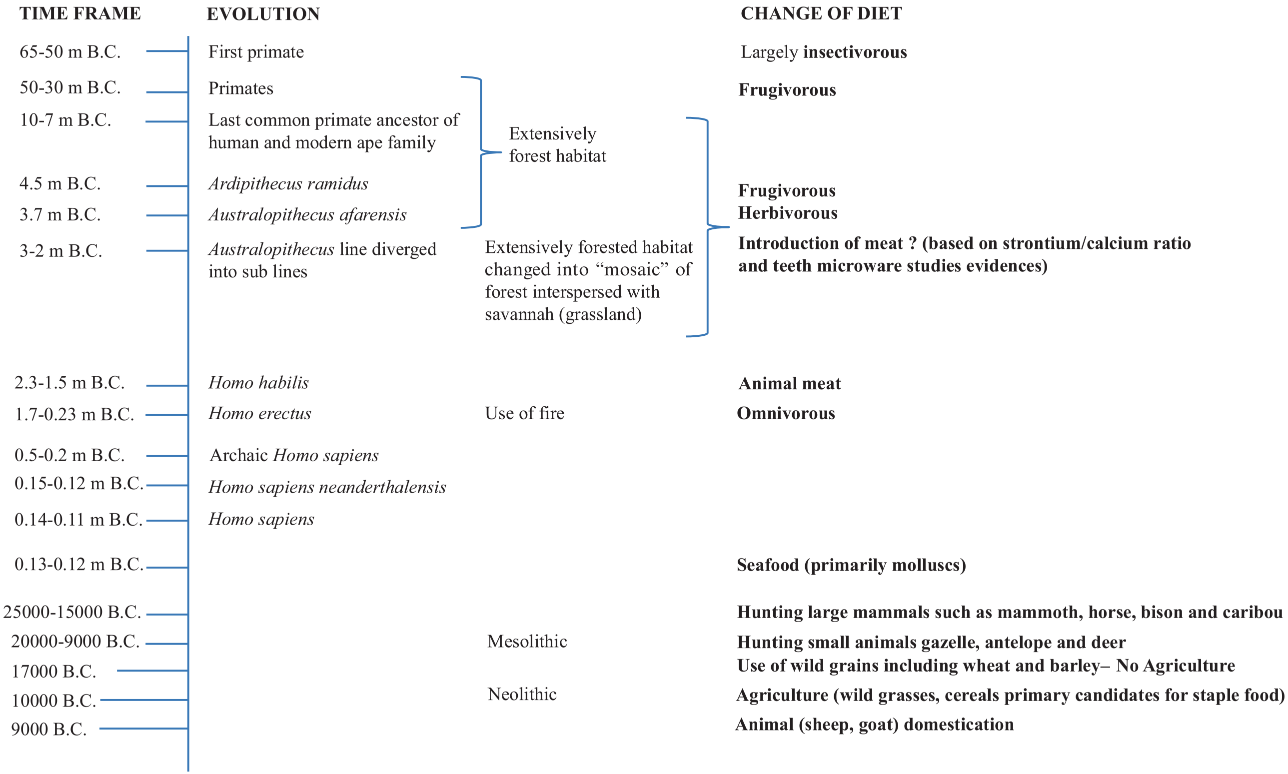


Fig. 1 Dietetic shift along with the evolutionary pathway

and there is a sharply increasing trend in the consumption rate of meat and dairy products worldwide. People in mainly western nations generally have higher protein consumption rates than those of developing nations and this stems mostly from the greater proportion of meat in their diet (Pimental et al. 1975; IEG Independent Expert Group 2016).

At present in developing countries with still rising populations, consumption of meat has been growing at 5–6% and that of milk and dairy products by 3.4–3.8% per annum (FAO 2015b). Meat-based food systems require more energy, land and water resources than the lacto-ovo-vegetarian diet system and in the long run the latter is more sustainable (Pimental and Pimental 2003). It has been pointed out that in order to slow down further global warming, deforestation, soil erosion and shortages of water availability, it is paramount to drastically reduce ruminant meat consumption (Koneswaran and Nierenberg 2008; Scholtz et al. 2013; Thornton 2010; Hedenus et al. 2014). However, to achieve that goal we believe it would be useful to explore and compare the food habits of different traditionally living groups of people and to understand their reasons for selecting particular food items out of the spectrum of food items available to them. An examination of the nutritional potential and sustainability of the specific food categories consumed by traditionally living communities would be desirable.

1.1 Insects as a Food Item

In this context we are giving priority to insects as almost 2 billion people worldwide consume these invertebrates as part of their diet and they possess a huge potential as farmed minilivestock (Paoletti 2005; Van Huis et al. 2013). Most persons, who have habitually eaten insects or who have started eating them recently do so, because they enjoy their taste (Megido et al. 2013; Deroy et al. 2015; House 2016). Moreover, the nutritional value of insects is no longer in doubt and they therefore appear to possess all the features one wishes an alternative food resource to have, as these and other analyses have demonstrated: Meyer-Rochow (1976), Ramos-Elorduy de Conconi et al. (1984), Ye et al. (2001), Yang et al. (2006), Finke (2002), Bukkens (1997, 2005), Malaisse (2005), Ghaly and Alkoaik (2010), Yhoung-Aree (2010), Fontaneto et al. (2011), Chakravorty et al. (2011a, 2014, 2016), Rumpold and Schlüter (2013), Ghosh et al. (2016, 2017).

One major problem, however, lies in the acceptability of insects in sections of people who did not traditionally consume them (Deroy et al. 2015). Since even amongst communities, whose members regularly consume insects, great differences exist between those that regard certain insects as tasty and edible, worthy of collecting and others that would reject these very species, considering them unfit for human consumption but accepting species avoided by the former community, we felt that finding answers to what governed the selection of an insect as an acceptable

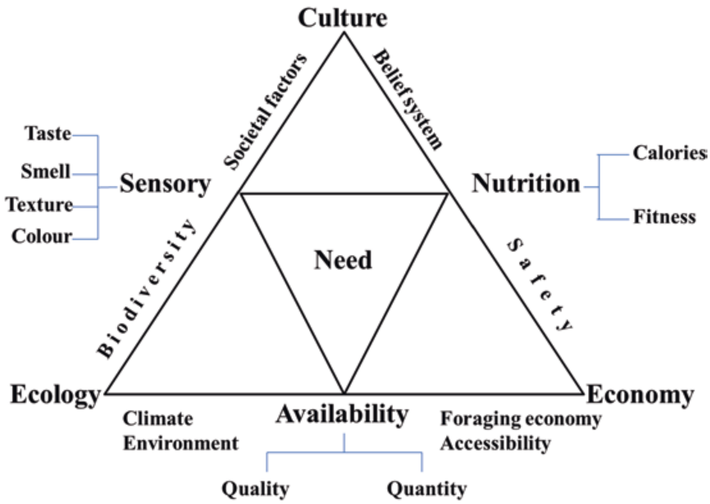


Fig. 2 Factors influencing food choice mechanism

food could also help us finding ways to popularize insects as human food and enlighten people of non-entomophagous societies about the merits of at least some food insects.

2 What to Select and What Not to Select

Since time immemorial, people have relied on the surrounding ecosystems as sources of their food, the most important prerequisite for life and health. What governed them then and still governs them now to distinguish between different food items, making them to accept some and reject others, remains a subject of scientific inquiry pertaining to both fundamental and applied research (Fig. 2). Vabø and Hansen (2014) distinguish food choices from food preferences and regard food preference as one of several other factors like health, price, convenience, mood, nutrient content familiarity, ethical concerns and sensory appeal that determine food choice. Smell, looks, texture and ultimately taste are considered to be among the most important drivers of both food choice (dietary habits) and food preferences, i.e. the selection of a particular food item out of a repertoire. However, the ease with which a particular type of food can be obtained, supply and demand, tradition, and ethical concerns, religious and other beliefs, etc., may further influence the choice (Lensvelt and Steenbekkers 2014). All of this is likely to apply to most of the various food sources, including, of course, insects.

Since selectivity is not only exhibited by humans, but also animals, clues on what governs selectivity are likely to be extractable from comparisons with animals and how and on what basis they carry out their food selections (Evans et al. 2015). Obviously anatomical and physiological characteristics of a species impose limitations on the food an organism might consider in its choices. A sheep might dearly want to reach and eat the fresh leaves of a tree, but it cannot climb. A cat would happily feast on an antelope, but it's not a lion and it lacks the size and strength of the latter to even consider prey as big as an antelope. A cat would also rather starve than to feed on leaves or grass, because its digestive system would be unable to handle the vegetarian diet and even within the guild of herbivorous ungulate species, food selection highly depends on how their digestive system can deal with high cellulose diets (Hanley 1982). Similar limitations would exist for invertebrate species so that one can categorically conclude that ecological and physiological constraints in combination with competition and natural selection are powerful factors in food selectivity. What these examples teach us further is that a food item not only has to be available, it also must be obtainable and the digestive system of the individual ingesting the food has to be able to handle it, i.e., seeing to it that the body can receive nutrients from it.

Monkeys are evolutionarily much closer to humans than cats and ungulates and like us are rather choosy, selecting their food items carefully. Spending time looking for food can be energetically demanding, which is why Emlen (1966) postulated that food selection is largely based on maximizing energy yield in relation to foraging time. Westoby (1974), however, felt that the primary foraging objective should be to optimize the nutrient mix within the available food spectrum. With regard to insects support for this notion comes from a study by Abrol (2007), in which plant cultivars with higher calorific rewards had the competitive edge over others in attracting foraging pollinator populations and therefore enjoyed better pollination successes. Milton (1979), studying howler monkeys and their food selection, found that these simians selected young leaves and preferred those with a high protein to fibre ratio. Frugivorous Bolivian spider monkeys on the other hand eat mostly figs and Felton et al. (2009) reported that their analyses of the chosen figs showed that the monkeys' food intake was "governed by protein-dominated macronutrient balancing".

This apparent preference of protein-rich items in howler and spider monkeys is somewhat surprising as primates are not known to possess specific protein taste receptors and therefore must have used other senses to distinguish protein-rich from protein-poor food. In fact Righini et al. (2015), also observing howler monkeys and their food choices for one year in the field concluded that with the exception of the time from October to January when the monkeys selectively collected fruits high in lipid content, no strong correlation with particular nutrients was apparent.

2.1 *Focusing on Humans*

What about humans then? Humans are believed to have evolved from frugivorous primates and although the diet of early hominins did not only consist of fruit, but very likely contained appreciable amounts of seeds and starch-rich underground plant items (Luca et al. 2010), an innate fondness of sweetness can be expected to have been present (Andrews and Martin 1991; Dudley 2000). Sweet fruit often contain insects and as the study by Bravo and Zunino (1998) with howler monkeys has shown, the latter do ingest, although not preferentially, some fig fruit with insect larvae. Many neotropical primates are known not just to eat fruits and leaves, but actively hunt insects, foremost and for all Orthoptera (Nickle and Heymann (1996), but old world monkeys, too, have been recorded as early as 1902 (baboons: pages 345, 382–383 in Marshall 1902) and 1921 (*Cercopithecus* sp.: Carpenter 1921) to appreciate many kinds of insects, but to avoid aposematically coloured ones (Carpenter 1921).

It does not seem far-fetched to assume that insect eating habits in humans followed a rather similar path to that sketched above for the monkeys, which is why Meyer-Rochow (2005) had suggested humans first ate insects together with picking sweet fruit. Other insects not associated with fruits, but collected because of their abundance, ease of access and, especially with regard to lipid-rich species, taste would also have mattered. To decide which species to take would have depended, apart from the season and availability of a species, on the collector's skill and equipment (if any was necessary) and personal preferences based on the palatability of the insect prey. Novelty-seeking, i.e. neophilia, may also have played a role (Miller 1997).

Reim (1962), reviewing entomophagous practices amongst Australian Aborigines, noticed that the latter showed a strong preference for fatty grubs and in contrast to tribal people of Papua New Guinea, just north of Australia, showed little interest in grasshoppers and locusts. Reim (1962) felt that the rest of the diet, especially that of desert inhabiting Aborigines, lacked sufficient amounts of lipids and concluded that that was the reason why they went for fat containing insects but also, it needs to be said, the highly esteemed honeypot ants and stingless honeybees, their brood and their products honey and wax reserved for the menfolk. In order to locate the bees and their prized "honeybag", as the locals call a bee's nest, an experienced trapper would listen to trees to find out if they were occupied by bees, poke sticks into a tree's holes and smell them to find out if there was some honey on them, and examine nearby spider webs for bee remains (Meyer-Rochow 1975a). It is obvious that the right tools and know-how are valuable assets in the procurement of specific species, something that also the studies of Laotian cricket and grasshopper collectors (Meyer-Rochow et al. 2008) and Japanese zazamushi collectors (Césard et al. 2015) show.

2.2 History and Ecology

Historically the consumption of insects was once widespread (Bergier 1941; Bodenheimer 1951), but the roots of human entomophagy, as we have just explained, are likely to go much deeper with roots in our primate ancestry (Fig. 1). Although this chapter has no intention to discuss the palaeo-anthropology of human origin or the anthropology of food and eating (Mintz and DuBois 2002), it is generally accepted that modern humans have evolved in Africa in a setting of tropical biodiversity, which would have included a great variety of insects as well as fruits. Thus, availability of both these food items and the occurrence of them together would have facilitated their joint uptake and acceptance by our human ancestors.

Early hominids then migrated to different geographical regions, some reaching temperate climes, where the lack of edible plant material, fruits (and associated insects) demanded of them to widen their food spectrum and include more and more animals as food. Humans benefitted from the degree of freedom that their genetically programmed taste preferences and their digestive system allowed them to have and it was this genetic scope that permitted them to expand their food experiences and food spectrum in ecologically different environments and habitats. Although our human ancestors' innate preference for sweet food items did not disappear, the attitude towards insects could have shifted from seeing them as a valued food item to regarding them more and more as vermin and to focus their food choice on larger and more fat-containing insect and animal species. More research is required to substantiate this hypothesis, because despite the harsh climate inhabitants of the high Arctic are known to have consumed a variety of insects and maggot-containing dishes (Freuchen 1961) and even during Roman times fat stag beetle and other timber boring larvae, collectively termed "cossus", were still relished (Holt 1885) while recipes of cockchafer soup were circulating in Germany as recent as 200 years ago.

Obviously an increasing awareness of insects as vectors of diseases, an association of insects with dirt and death, with witchcraft and poverty is likely to have led to a greater alienation and more widespread fear and disgust of insects as food especially in western societies, although -and this is often overlooked- locusts are singled out as kosher in the Bible (Leviticus Chpt. 11:21), and thus had to be regarded as acceptable food by Jews, Christians and Muslims alike. To what extent the consumption of maggot-containing cheese (e.g., known as "casu marzu" in Sardinia) or mite cheese (known as "Milbenkäse" in Germany) is rooted in ancient entomophagous habits and represents remnants of a once more widespread consumption of arthropods in Europe is debatable, just like the behaviour of some children in Finland is to kill and suck out bumblebees on account of their sweetish taste. How such habits developed and became a tradition is unknown, but a positive experience must have been involved. To cite another example, a section of North East Indians prefer to eat maggot-containing soybean and consider that a delicacy. However, an indisputable fact, true for the northern as well as the southern hemisphere, is that the decline in insect variety from climatic zones favourable to insects to those unfavourable to them, is paralleled by a decline in species deemed consumable and worth collecting.

2.3 Culture

Cultural experience plays a significant role in determining the acceptability and preference of food. There are many examples of the acceptance of one insect species food by one tribe or a population of one region but considered non-edible by neighbouring tribes. *Zonocerus* spp. (grasshopper) are considered edible in the Republic of South Africa, Cameroon and Nigeria, but considered poisonous elsewhere (Schabel 2010; Van Huis et al. 2013); *Phymateus viridipes* is edible in Zambian region but not elsewhere (Malaisse 1997) and even in areas of close geographic proximity as in Arunachal Pradesh, India, some scarab beetles are considered edible by one tribal community, but rejected by another ethnic group nearby (Chakravorty et al. 2011b, 2013). Many insects are known to sequester a wide range of phytochemicals of differential toxicity and perhaps this would be one of the reasons to taboo some insects by certain ethnic communities. However, the processing or modes of preparation of these insects are remarkable and reflect a rich traditional knowledge base. In Cameroon and Nigeria *Zonocerus variegatus* (variegated grasshopper) are prepared in a specific way by heating the insect in tepid water and changing the water before cooking (Barreteau 1999; Morris 2004). In a rather similar way soybean is prepared to remove anti-nutritional compounds like, for example, trypsin inhibitor.

Koivisto-Hursti (1999) has documented that with regard to food choice, children follow their parents and that this is the main way food habits become stabilized in the community. Once established, food traditions are often extremely persistent, hard to break (Meyer-Rochow 1998) and an integral part of a culture (Rozin 2007b). The "learning experience" (= getting used to a novel food) has been highlighted by Nestle et al. (1998) and Ventura and Worobey (2013) as an important factor in the development and persistence of food preferences from generation to generation. However, it ought to be mentioned here that food preferences can change as people get older and begin to suffer from dental problems and illnesses that render the consumption of certain foods, once relished, undesirable (cf., Koehler and Leonhaeuser 2008).

This cultural influence dominated the selection of preferred species and how they should be prepared, e.g., raw, pickled, roasted, fried, steamed, boiled in tests conducted by Tan et al. (2015) on probands from Thailand and the Netherlands, who had and had not eaten insects before. Individual rather than cultural experience determined "whether judgements were made based on memories of past eating experiences or based on the visual properties and item associations" (Tan et al. 2015). It can be argued that acceptance by one and rejection by another group, removes pressure on the resource and makes good sense in the perspective of ecological sustainability. Such "division of acceptability" may, however, not have been consciously planned or designed to safeguard the availability of the species in question, but may have evolved to underscore the cultural separateness, the distinctiveness of neighbouring cultural groups as unique entities. Thus, acceptability of some species of insects then became a tradition, a symbol, decoupled, for instance, from utilitarian motifs like nutrition and availability.

Gender-based taboos in order to unite and distinguish one sector of the community from another are also not exactly rare. Women of the Baganda tribe of Uganda, for example, are prohibited by custom from consuming long horned grasshoppers (katydids) commonly known as 'nsenene'. Women and children, however, are the main collectors of these insects and the women cook them for their husbands. It is a common tradition amongst the Baganda to offer 'nsenene' to their male guests (S, Ghosh, unpublished). Amongst a variety of northeastern Indian tribes, women are advised not to get touched by certain species of cicada (Chakravorty et al. 2011b). In both cases, consumption of the insects in question by women of reproductive age is presumed to affect a baby's development, an assumption for which no scientific evidence exists.

That taboos imposed by religious and other beliefs (or authorities of any sort) on whole communities or subsections of the population often influence what is and what is not acceptable as food during certain times of the year has been discussed in more detail by Meyer-Rochow (2009) and is undoubtedly applicable to many more insects than grasshoppers and cicadas. However, what complicates the matter is that frequently it does not come into the mind of people (who consume what the scientist would identify as "an insect") that they have actually been ingesting insects regularly. When questioned as to whether they would eat insects at all, they would then often reply that they never did and never would, even if in fact they had just swallowed some. Although their response could be influenced by who poses the question to them and whether they are shy, it is a fact, observed by other researchers as well, that their attitude to see edible insects not as insects, but as an ordinary kind of food is widespread, and thus, in their minds, represent something quite different from "true" insects, which they would not dream of consuming (Evans et al. 2015).

3 Sensory Characteristics

3.1 Taste

In the context of a discussion on food selection governed by sensory characteristics taste has to receive primary attention. Interestingly, the word disgust has its root in "dis" (= opposite, negating 'the acceptable') and "gust" (= gut, digestive system, also part of the words 'gastronomy', 'gaster', 'gastric', etc.), which shows the importance of food intake and attitude. Taste, as the final control, determines whether a food item will be allowed to enter the body, the "gut", or not. There is good evidence to believe that all humankind possess the same kinds of taste receptors (Tuorila 2007), but this does not necessarily mean that substances taste the same way to everyone as the well-known case of PTC (phenyl-thio-carbamide) tasters and non-tasters demonstrates (one third of Europeans are non-tasters, the remainder are tasters: Lawless and Heymann 2010).

Our liking of sweet and dislike of bitter tastes are considered innate human traits, thought to be the result of a biological coding for 'safe' versus 'dangerous' foods. Sequestered plant toxins if stored in an insect will cause the insect to be judged unpalatable (Berenbaum 1993). Taste receptors for sugary substances occupy a prominent position on the human tongue and children the world over can be pacified with sweets. In Carina of northern Italy, children traditionally eat ingluvies of the moth *Zygaena*, which have a sweetish taste (Zagrobelny et al. 2009). This moth species is potentially toxic, because it contains cyanogenic glucosides, which release toxic hydrogen cyanide upon degradation (Zagrobelny et al. 2009). Benzoquinones and hydrogen cyanide are also released by millipedes like *Tymbodesmus falcaus, Sphenodesmus sheribongensis* and an unidentified spirostrepsid species, which are accepted as food by the Bobo people of Burkina Faso in spite of the unpleasant chemicals they contain (Enghoff et al. 2014).

Another characteristic of the food item that is involved in the decision of whether or not to accept and swallow it would be its texture, for which, as with taste, contact receptors in the mouth (or the fingers as well) are required. Odour and looks of a food item can be gauged from the distance by olfactory and visual receptors and are characteristics that facilitate long range detection of and attraction to the food item in question, especially if the consumer has learned to associate these characteristics with an earlier positive taste experience.

Obviously, taste preferences are to some extent culturally conditionable and this has already been underscored with some of the examples given above. The genetically laid down wide bracket of taste tolerance in humans and a digestive system able to accommodate a great variety of food stuffs, therefore, have to be seen as responsible for human beings to extend the range of nutritious substances they select from the environment. Size, shape, smell and visual appearance, and especially a food item's colour, are other sensory properties that further influence the selection and preference of foods, including insects, but which need to be discussed separate from taste.

3.2 Odour

The first cranial nerve in humans (and other vertebrates) is the olfactory nerve and a human's sense of smell is vastly more sensitive than that of taste. The smell of a food item is therefore not only important as a means to detect it from a distance even when it cannot be seen; it also provides a human with the possibility to pre-assess a food item with regard to its acceptability as edible or not, especially in combination with a learned response from an earlier experience. Although putrid and foul smells of vomit, faeces and decaying corpses are universally abhorred, some smells like those of fish, roasts, cheese, cabbage, and fermented foods, etc. are appreciated by some, but avoided by others and, once again, show our human's ability to expand tolerance limits in connection with adapted customs.

Stink bugs are a case in point: pungent and bad-smelling, these pentatomid bugs are nevertheless a favourite food item for many insect-eating people in parts of Asia (Chakravorty et al. 2011a) and Africa (Teffo et al. 2007). They demonstrate afresh the range of stimuli that are able to signify acceptability of a food item to some people, but not others.

3.3 Visual Appearances

Animals often either instinctively or through experience appear to know that the coloration of certain flowers, fruits, mushrooms and animals acts as a deterrent or warning and avoid consuming and sometimes even touching such species. More than 90 years ago Carpenter (1921) carried out experiments to examine the reactions of two monkeys towards different insect species, some aposematically coloured and some not. The experiment revealed that the monkeys made no attempt to eat brightly and aposematically coloured insects like, for example, *P. viridipes* (green milkweed locust or African bush grasshopper) and *Zonocerus elegans* (elegant grasshopper), but readily accepted others. Since both of these species were considered non-edible and poisonous by large numbers of people in various parts of Africa, the still unresolved question arises as to whether these humans also knew instinctively to avoid certain species or had observed and copied the behaviour of simians or perhaps had learned from personal experience and taught other members of the community.

Coloration, however, at least for humans and those animals that possess colour vision, does more than indicate whether a food item is dangerous to health or not. It can provide information on the developmental stage, the amount of sugar or fat in a food item and in this way indicate whether the food item is worth the trouble collecting it. Since different developmental insect stages and even genders can be of different shapes and coloration, discriminating highly appreciated stages or individuals from lesser valued ones in this way is facilitated.

3.4 Texture

In a pre-selection process to decide whether an item can possibly be considered edible and accepted as food, a closer inspection and an assessment of its texture are also important steps. Items with a prickly, rough surface receive considerably less attention than items with a smooth and seemingly softer outside. For example, in insects with spiny appendages, the latter are carefully removed before a person proceeds to prepare such insects further for consumption. There is apparently good reason to take such precautionary measures, for Bouvier (1945) observed that in what is now the Democratic Republic of Congo people who consumed grasshoppers and locusts without removing their legs could suffer from constipation or difficulties in swallowing, caused by the large indigestible chitinous spines on the tibiae of these insects. Sometimes surgery was required to remove the obstruction. Rather similar cases were reported by Kuyten (1960) from Eastern Java (Indonesia) following consumption by the locals of large scarab beetles.

4 Plasticity of Sensory Perception

As mentioned earlier, humans all over the world, despite possessing the same gustatory receptors and basic needs of protein, fat, carbohydrates, minerals and vitamins, display huge differences with regard to those food items they consider tasty or at least acceptable. The fundamental reason for this variety in food preferences is the range of freedom in tolerating widely different levels of what is considered sweet, sour, salty and bitter and a digestive system that can handle a wide range of food items (with the exception of cellulose-rich ones like grass and wood). Given prolonged voluntary or forced exposure to what at first might have been a distasteful flavour or disgusting smell, then this initially unpleasant experience can turn not just into acceptance, but can lead to a preference of the otherwise objectionable taste or smell.

Stink bugs belonging to the family Pentatomidae, mentioned earlier, do not seem to be a promising food candidate given their pungent smell. Yet, these bugs are a favourite food item to a large section of ethnic people of North East India, Indochina (Chakravorty et al. 2011a) and parts of Africa (Teffo et al. 2007). Carpenter (1921) observed that “the odour that to us seems so very unpleasant does not appear to be considered a distasteful quality by the monkeys”, who relished *Anoplocnemis curvipes* bugs in spite of their smell. Other examples are fermented bamboo shoots or stored soybeans containing maggots, foods -that just like the famous maggot-containing” casu marzu” in parts of Italy- are considered very delicious amongst members of some ethnic groups in the north-eastern part of India, but rejected as inedible by those who are not accustomed to these items (S. Ghosh, unpublished).

4.1 Nutritional Aspect

The concept of what represents a ‘healthy nutrition’, a ‘balanced diet’ is something that only rather recently has become to occupy a prominent factor in the choice of food items. Yet, even today traditions exert a powerful influence on what people eat and therefore the value given to uphold dietary tradition often outweighs that which nutrition experts attach to certain food items. In this context disagreements between food experts and confusing changes in the recommendations of what ought to be avoided and what should be eaten do not help to convince people to abandon religious doctrine, traditions and superstition. For a while, meat consumption was propagated as an almost essential way to obtain sufficient protein to stay healthy, but then a vegetarian diet with legumes and milk as suppliers of essential nutrients was recommended as superior. As of late, insects as a protein source are now gaining more and more support from ecologically minded food experts.

Despite two comprehensive reviews on the uses of insects as food amongst the different peoples of the world (Bergier 1941; Bodenheimer 1951) and a shorter summary by Hoffman (1947), the question of "Why not eat insects?", first raised by Holt (1885), was not revived until exactly 90 years later by Meyer-Rochow (1975b), who asked "Can insects help to ease the problem of world food shortage?". Ever since then, the notion that insects can indeed help, has been gaining momentum and nutritional analyses have further strengthened the idea that insects have a role to play as an alternative especially to mammalian meat. Future food security is seen as one of the biggest challenges of the world of today and insects containing high amounts of protein, valuable and easily digestible fats, relatively low carbohydrate content, small but significant amounts of important minerals and essential vitamins are not only abundant and easy to breed in large quantities in farms that occupy a fraction of the land used for ruminant livestock, they are, with few exceptions, also a very healthy food item (Ladron de Guevara et al. 1995; Bukkens 1997; Banjo et al. 2006; Yhoung-Aree 2010; Chakravorty et al. 2014; Kouřimska & Adámková 2016; Sabolová et al. 2016; Ghosh et al. 2017).

Although the adult insects' exoskeleton can be very hard and tough, consisting of an approximately 50:50 ratio of the carbohydrate chitin and protein (Peters 2003), it adds roughage to the food and, according to Goodman (1989) and Lee et al. (2008), is credited with cancer-preventive properties and an ability to strengthen the immune system, respectively. The widely held belief that it is totally indigestible in humans may not actually be correct, because the gastric juice of a sizeable proportion of humans tested by Paoletti et al. (2007) has been found to contain chitinase, which can degrade chitin. The absence of the activity in 20% of the Europeans tested is explained by the research time as a consequence of the virtual absence of chitin-containing food items in the western diet.

Needless to say that any large scale promotion of insects as human food, to name but a few fields, needs to take into consideration possible ecological effects of significant numbers of insects removed from nature (Meyer-Rochow 2010), possible effects like allergies and incompatibilities with medication, transmission of parasites and diseases affecting the human consumer (Dobson and Carper 1996; Inceara and Türkez 2009; Sun-Waterhouse et al. 2016), digestibility, shelf life, storage and preservation of food insects (Gorham 1976, 1979; Belluco et al. 2013), production costs and retail prices (Meyer-Rochow et al. 2008; Halloran et al. 2016). Future uses of farmed insects could also include feeding them to for example poultry, or establishing cultures of insect cell lines and tissues. However, as with the promotion of the direct use of insects as human food, a considerable amount of additional research would be required.

4.2 Ethno-Scientific Perspective

Obviously before humans had acquired the knowledge to make fire, all foods were eaten raw and those that caused unwellness or worse were avoided. Boiling and roasting not only made some foods tastier, they also allowed some foods to be used that were avoided before, because boiling, for instance, would destroy toxins, soften tissues, intensify tastes and promote digestibility. Holt (1885), who has tasted both raw and cooked locusts and found them "raw…pleasant to the taste; cooked they are delicious". To find ways to improve the taste of insects would have led to the discovery of detoxifying methods. In Cameroon and Nigeria the orthopteran *Zonocerus variegates* is prepared for consumption by heating the insects in tepid water and changing the water before cooking (Barreteau 1999; Morris 2004). Another example is the preparation process of the edible tessaratomid stinkbug *Encosternum* (= *Natalicola*) *delegorguei*, whose pungent defensive liquid can cause severe pain and even blindness if accidentally rubbed into the eye. Consumers of this insect in Zimbabwe and South Africa therefore remove the fluid from the insect by squeezing the insect's thorax prior to further processing (Scholtz 1984). Similar manipulations were sometimes, but not always, carried out by people in North-East India, prior to the consumption of the ghondibug *Aspongopus nepalensis* (Chakravorty et al. 2011a). However, not always are harmful substances removed and even today insect-consuming people often prefer to eat some species raw, in spite of their toxic substances as with *Zygaena* (Zagrobelny et al. 2009) and millipedes (Enghoff et al. 2014).

5 Economy

So far we have focused on likely factors involved in choosing specific insects as food and have tried to put forward our ideas to understand the continuation as well as the discontinuation of this practice among different societies to this present day. Our discussion would be incomplete if we ignored the 'economy' issue to understand the present scenario of insects as a food item with a future. Economic aspects are of overwhelming importance in present day affairs, trigging and influencing especially all facets of trade (Müller et al. 2016). Therefore, what we cannot ignore is the association especially by people with western cultural backgrounds between entomophagous habits and regions of relatively low economic status, adverse or extreme climatic conditions, widespread areas of sterile or infertile land, frequent water shortages, alarming nutrient deficiencies and limited health services. Almost certainly such associations nurture feelings of fear and disgust (Rozin et al. 2008; Barrena and Sanchez 2013; Deroy et al. 2015) and serve as psychological barriers (Looy et al. 2014).

Perhaps for reasons like this, insects until very recently have not received much attention as a food resource and scientists advocating them as a resource were not taken seriously, but now insects have begun to be viewed as a sustainable solution in the context of future food security. The more people find insects as food or addition to familiar foods acceptable, the more will dare to at least try them and then, perhaps, accepting them as a food item whereby they would be setting an example for others (cf. tests on familiar and unfamiliar foods by Pliner and Hobden 1992; Pliner and Mann 2004; Martins and Pliner 2005; Siegrist et al. 2013 have shown that food neophobia is negatively correlated with familiarity). Pre-historic humans started using insets as food by collecting their insects from the wild, a practice still common in parts of the world, but now considered as ecologically no longer advisable in view of an expanding food insect demand. We therefore strongly believe that foraging insects from the wild should give way to systematic farming practices with predictable and controllable regular harvests of the edible insect crop.

Beginnings of such thinking can be traced back to the practice of West Australian Aborogines to physically damage the host trees of the cerambycid beetle *Bardistus cibarius*, so that it may breed there and its grubs, known as 'bardy worms', could later be harvested and conserved for future uses by drying and/or roasting (Reim 1962). Another example comes from the manipulation of host trees for the procurement of palm weevils in Papua New Guinea, where the weevil's larvae are considered a delicacy (Mercer 1994) and from Japan where attempts to cultivate edible wasps have been taking place (Payne and Evans 2017). The best examples, however, are apiculture (beekeeping) and sericulture (rearing of silkworms), both of which have long historical associations with human civilizations. Despite this long association with silkworms and honey bees, most of the other insects until recently were not seen to satisfy the conditions of being domesticated. That this attitude has begun to change is demonstrated by the semi-domestication of bumblebees as pollinators and the farming of certain edible insect species, e.g. crickets (Halloran et al. 2016).

Almost certainly with the increasing awareness of the nutritional and environmental benefits of expanding the circle of insect eating humans, the global demand for edible insects will rise, offering opportunities "to make money" and develop businesses in connection with the new trend. So-called cricket bread, for example, sold as 'sirka leipä' in Finland and containing 3 % cricket flour is already available. Thus, there will be an emphasis on some species based on the available knowledge of their nutritive value, their life cycle details and suitability for farming and semi-domestication. Today the commercial sector has already begun to develop methods permitting the large scale production of certain edible insect species like mealworms (*Tenebrio molitor*.), crickets (*Teleogryllus commodus*, *Gryllus bimaculatus*), and so-called 'white grubs' (*Protaetia cinarea*) etc. However, it is self-understood that not all of the 2000 insects currently regarded as edible (Mitsuhashi 2008; Jongema 2015) will receive the same attention in efforts to rear them in insect farms, but at the same time one must not overemphasise one or a handful of species and neglect other possible and promising candidates. One also needs to carefully consider the removal of species from their original geographic habitat locations to other regions for rearing them, since individuals could escape and become established in their new surroundings as invasive and environmentally undesirable newcomers.

6 Conclusion

In summary, we do see a bright future for certain species of insects as a novel and gradually more and more globally acceptable food item, but attempts to popularize insects as food should bear in mind our finding that even traditionally insect consuming cultures vary with regard to the choices they make in accepting species as edible and that there are reasons for these differences. Transdisciplinary research approaches involving biological as well as social sciences and other disciplines are greatly needed in order to achieve an in depth understanding of the various complex interactions that determine acceptance or rejection of a food item (Fig. 2). Attempts to popularize food insects by focusing only on one or two species, e.g., mealworms and crickets, could therefore lead to some difficulties in certain sections of the potential clientele and other species, e.g. grasshoppers must not be forgotten (Paul et al. 2016). Consideration ought to be given to the differences in food choice and food preference criteria outlined in this paper and insect farming enterprises need to be tailored to the expectations of the clientele and in harmony with the geographic location and environment they operate in.

References

Abrol DP (2007) Foraging behaviour of *Apis mellifera* L. and *Apis cerena* F. As determined by the energetic of nectar production in different cultivars of *Brassica campestris* var. *toria*. J Apic Sci 51:19–23

Andrews P, Martin L (1991) Hominoid dietary evolution. Philos Trans R Soc Lond Ser B Biol Sci 334:199–209

Banjo AD, Lawal OA, Songomuga EA (2006) The nutritional value of fourteen species of edible insects in southwestern Nigeria. Afr J Biotechnol 5:298–301

Barrena R, Sanchez M (2013) Neophobia, personal consumer values and novel food acceptance. Food Qual Prefer 27(1):72–84

Barreteau D (1999) Les Mofu-Gudur et leurs criquets. In: Baroin C, Boutrais J (eds) L'homme et l'animal dens le basin du lac Tchad: actes du colloque du reseau Méga-Tchad. Institut de Recherche pour le Development, Universite Nanterre, Paris, pp 133–169

Belluco S, Lossasso C, Maggioletti M et al (2013) Edible insects in a food safety perspective: a critical review. Compr Rev Food Sci Food Saf 12:296–313

Berenbaum MR (1993) Sequestered plant toxins and insect palatability. Food Insect Newsl 6:1–9

Bergier E (1941) Peuples entomophages et insects comestibles: étude sur les moeurs de l'homme et de l'insecte. Imprimérie Rullière Frères, Avignon

Bible. – Leviticus Chpt 11, 21

Bodenheimer FS (1951) Insects as human food. W. Junk Publ, The Hague

Bouvier G (1945) Quelques questions d'entomologie vétérinaire et lute contre certains arthropodes en Africa tropicale. Acta Trop 2:42–59

Bravo SP, Zunino GE (1998) Effects of black howler monkey (*Alouatta caraya*) seed ingestion on insect larvae. Am J Primatol 45:411–415

Bukkens SGF (1997) The nutritional value of edible insects. Ecol Food Nutr 36:287–319

Bukkens SGF (2005) Insects in the human diet: nutritional aspects. In: Paoletti MG (ed) Ecologcical implications of minilivestock. Science Publishers, Enfield, pp 545–578

Carpenter GDH (1921) Experiments on the relative edibility of insects with special reference to their coloration. Trans R Ent Soc Lond 54:1–105

Césard N, Komatsu S, Iwata A (2015) Processing insect abundance: trading and fishing of zazamushi in central Japan (Nagano prefecture, Honshu Island). J Ethnobiol Ethnomed 11:78. https://doi.org/10.1186/s13002-015-0066-7

Chakravorty J, Ghosh S, Meyer-Rochow VB (2011a) Chemical composition of *Aspongopus nepalensis* Westwood 1837 (Hemiptera; Pentatomidae), a common food insect of tribal people in Arunachal Pradesh (India). Int J Vitam Nutr Res 81:48–56

Chakravorty J, Ghosh S, Meyer-Rochow VB (2011b) Practices of entomophagy and entomotherapy by members of the Nyishi and Galo tribes, two ethnic groups of the state of Arunachal Pradesh (north-East India). J Ethnobiol Ethnomed 7:5. https://doi.org/10.1186/1746-4269-7-5

Chakravorty J, Ghosh S, Meyer-Rochow VB (2013) Comparative survey of entomophagy and entomotherapeutic practices in six tribes of eastern Arunachal Pradesh (India). J Ethnobiol Ethnomed 9:50. https://doi.org/10.1186/1746-4269-9-50

Chakravorty J, Ghosh S, Jung C et al (2014) Nutritional composition of *Chondacris rosea* and *Brachytrupes orientalis*: two common insects used as food by tribes of Arunachal Pradesh, India. J Asia Pac Entomol 17:407–415

Chakravorty J, Ghosh S, Megu K et al (2016) Nutritional and anti-nutritional compostion of *Oecophylla smaragdina* (hymenoptera: Formicidae) and *Odontotermes* sp. (Isoptera: Termitidae): two preferred edible insects of Arunachal Pradesh, India. J Asia Pac Entomol 19:711–720

Deroy O, Reade B, Spence C (2015) The insectivore's dilemma, and how to take the west out of it. Food Qual Prefer 44:44–55

Dobson AP, Carper ER (1996) Infectious diseases and human population history. Bio Sci 46:115–126

Dudley R (2000) Evolutionary origins of human alcoholism in primate frugivory. Q Rev Biol 75:3–15

Emlen JM (1966) The role of time and energy in food preference. Am Nat 100:611–617

Enghoff H, Manno N, Tchibozo S et al (2014) Millipedes as food for humans: their nutritional and possibly antimalarial value – a first report. Evid Based Complement Alternat Med. https://doi.org/10.1155/2014/651768

Evans J, Alemu MH, Flore R et al (2015) 'Entomophagy': an evolving terminology in need of review. J Insects Food Feed 1:293–305

FAO (2014a) Food security indicators. http://www.fao.org/economic/ess/ess-fs/essfadata/en

FAO (2014b) How to feed the world in 2050? http://www.fao.org/fileadmin/templates/wsfs/focs/expert_paper/How_to_Feed_the_World-in_2050.pdf. Accessed 7 Dec 2012

FAO (2015a) The state of food insecurity in the world 2015. http://www.fao.org/3/a-i4646e.pdf. Accessed 28 Jan 2017

FAO (2015b) World agriculture: towards 2015/2030. An FAO perspective. http://www.fao.org/3/a-y4252e.pdf. Accessed 31 Jan 2017

Felton AM, Felton A, Wood JT et al (2009) Nutritional ecology of *Ateles chamek* in lowland Bolivia: how macronutrient balancing influences food choices. Int J Primatol 30:675–697

Finke MD (2002) Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biol 21:269–285

Fontaneto D, Tommaseo-Ponzetta M, Galli C et al (2011) Differences in fatty acid compositions between aquatic and terrestrial insects used as food in human nutrition. Ecol Food Nutr 50:351–367

Freuchen P (1961) Book of the Eskimos. Fawcett Crest Book, Greenwich

Ghaly AE, Alkoaik FN (2010) Nutritional value of the maize stalk borer and American bollworm as unconventional protein sources. Am J Appl Sci 7:1–12

Ghosh S, Jung C, Meyer-Rochow VB (2016) Nutritional value and chemical composition of larvae, pupae, and adults of worker honey bee, *Apis mellifera* as a sustainable food source. J Asia Pac Entomol 19:487–495

Ghosh S, Lee S-O, Jung C, Meyer-Rochow VB (2017) Nutritional composition of five commercial edible insects in South Korea. J Asia Pac Entomol 20:685–694

Goodman WG (1989) Chitin: a magic bullet? Chitin credited with cancer-preventive properties. Food Insect Newsl 2:2

Gorham R (1976) Insects as food. Bull Soc Vector Ecol 3:11–16

Gorham R (1979) The significance for human health of insects in food. Annu Rev Entomol 24:209–224

Halloran A, Roos N, Hanboonsong Y (2016) The development of the edible cricket industry in Thailand. J Insect Food Feed 2:91–100

Hanley TA (1982) The nutritional basis for food selection by ungulates. J Range Manag 35:146–151
Hedenus F, Wirsenius S, Johansson DJA (2014) The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Clim Chang 124:79–91
Hoffman WE (1947) Insects as human food. Proc Entomol Soc Wash 49:233–237
Holt V (1885) Why not eat insects? Pryor Publications, Whitstable
House J (2016) Consumer acceptance of insect-based foods in the Netherlands: academic and commercial implication. Appetite 107:47–58
IEG Independet Expert Group (2016) Global Nutrition Report 2016: from promise to impact, ending malnutrition by 2030. http://www.globalnutritionreport.org. Accessed 15 Sept 2017
Inceara Ü, Türkez H (2009) The genotoxic effects of some edible insects on human whole blood cultures. Mun Ent Zool 4:531–533
Jongema Y (2015) List of edible insects of the world. http://bit.ly/1wbQojQ. Accessed 15 Aug 2015
Koehler J, Leonhaeuser IU (2008) Changes in food preferences during aging. Ann Nutr Metab 52(suppl 1):15–19
Koivisto-Hursti U (1999) Factors influencing children's food choice. Ann Med 31(suppl 1):26–32
Koneswaran G, Nierenberg D (2008) Global farm animal production and global warming: impacting and mitigating climate change. Environ Health Perspect 116:578–582
Kouřimska L, Adámková A (2016) Nutritional and sensory quality of edible insects. NFS Journ 4:22–26
Kuyten P (1960) Darmafsluiting veroorzakaat door het eten van kevers. Entomol Ber 20:143
Ladron de Guevara O, Padilla P, Garcia L et al (1995) Amino acid determination in some edible Mexican insects. Amino Acids 9:161–173
Lawless HT, Heymann H (2010) Sensory evaluation of food. Springer, Berlin
Lee CG, Silva CAD, Lee J-Y et al (2008) Chitin regulation of immune responses: an old molecule with new roles. Curr Opin Immunol 20:684–689
Lensvelt EJS, Steenbekkers LPA (2014) Exploring consumer acceptance of entomophagy: a survey and experiment in Australia and the Netherlands. Ecol Food Nutr 53:543–561
Looy H, Dunkel FV, Wood GR (2014) How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric Human Values 31(1):131–141
Luca F, Perry GH, Di Rienzo A (2010) Evolutionary adaptations to dietary changes. Annu Rev Nutr 30:291–314
Malaisse F (1997) Se nourir en forêt Claire africaine: approache écologique et nutritionnelle. Gembloux Les Presses, Agronomiques de Gembloux
Malaisse F (2005) Human consumption of Lepidoptera, termites, Orthoptera, and ants in Africa. In: Paoletti MG (ed) Ecological implications of minilivestock – potential of insects, rodents, frogs and snails. Science Publishers, Enfield, pp 175–230
Marshall GAK (1902) Five years' observations and experiments (1896-1901) on the bionomics of south African insects, chiefly mimicry and warning colours. Trans Entomol Soc Lond 1902:287–584
Martins Y, Pliner P (2005) Human food choices: an examination of the factors underlying acceptance/rejection of novel and familiar animal and non-animal foods. Appetite 45:214–224
Megido RC, Sablon L, Geuens M, Brostaux Y, Alabi T, Blecker C, Drugmand D, Haubruge E, Francis F (2013) Edible insects acceptance by Belgian consumers: promising attitude for entomophagy development. J Sens Stud 29:14–20
Mercer CWL (1994) Sago grub production in Labu swamp near Lae, Papua New Guinea. Klinkii 5:30–34
Meyer-Rochow VB (1975a) Local taxonomy and terminology for some terrestrial arthropods in five different ethnic groups of Papua New Guinea and Central Australia. J R Soc West Aust 58:15–30
Meyer-Rochow VB (1975b) Can insects help to ease the problem of world food shortage? Search 6:261–262
Meyer-Rochow VB (1976) The use of insects as human food. Food Nutr 33:151–152

Meyer-Rochow VB (1998) Ethnic identities, food and health. Int J Circumpolar Health 57:2–3
Meyer-Rochow VB (2005) Traditional food insects and spiders in several ethnic groups of Northeast India, Papua New Guinea, Australia, and New Zealand. In: Paoletti MG (ed) Ecological implications of minilivestock – potential of insects, rodents, frogs and snails. Science Publishers, Enfield, pp 385–409
Meyer-Rochow VB (2009) Food taboos: their origins and purposes. J Ethnobiol Ethnomed 5:18. https://doi.org/10.1186/1746-4269-5-18
Meyer-Rochow VB (2010) Entomophagy and its impact on world cultures: the need for a multidisciplinary approach. In: Durst PB, Johnson DV, Leslie RN et al (eds) Forest insects as food: humans bite back, RAP public 2010/02. FAO, Bangkok, pp 23–36
Meyer-Rochow VB, Nonaka K, Boulidam S (2008) More feared than revered: insects and their impact on human societies (with some specific data on the importance of entomophagy in a Laotian setting). Entomol Heute 20:3–25
Meyer-Rochow VB, Megu K, Chakravorty J (2015) Rats: if you can't beat them eat them! (tricks of the trade observed among the Adi and other north-east Indian tribals). J Ethnobiol Ethnomed 11:45. https://doi.org/10.1186/s13002-015-0034-2
Miller GF (1997) Protean primates: the evolution of adaptive unpredictability in competition and courtship. In: Whiten A, Byrne RW (eds) Machiavellian intelligence II: extensions and evaluations. Cambridge University Press, Cambridge, pp 312–340
Müller A, Evans J, Payne CIR, Roberts R (2016) Entomophagy and power. J Insects Food Feed *2*(2):121–138
Milton K (1979) Factors influencing leaf choice by howler monkeys: a test of some hypotheses of food selection by generalist herbivores. Am Nat 114:362–378
Mintz SW, DuBois CM (2002) The anthropology of food and eating. Annu Rev Anthropol 31:99–119
Mitsuhashi J (2008) Sekai konchuu shoko taizen. Yasaka Shobo, Tokyo
Morris B (2004) Insects and human life. Berg, Oxford
Nestle M, Wing R, Birch L et al (1998) Behavioral and social influences on food choice. Nutr Rev 56:50–74
Nickle DA, Heymann EW (1996) Predation on Orthoptera and other orders of insects by tamarind monkeys, *Saguinus mystax mystax* and *Saguinus fuscicollis nigrifrons* (primates: Callitrichidae) in north-eastern Peru. J Zool (London) 239:799–819
Paoletti MG (2005) Ecological implications of minilivestock: potential of insects, rodents, frogs, and snails. Science Publishers, Enfield
Paoletti MG, Norberto L, Damini R et al (2007) Human gastric juice contains chitinase that can degrade chitin. Ann Nutr Metab 51:244–251
Paul A, Frederich M, Uyttenbroek R, Hatt S, Malik P, Lebecque S, Hamaidia M, Miazek K, Goffin D, Willems L, Deleu M, Fauconnier ML, Richel A, DePauw E, Blecker C, Monty A, Francis F, Haubruge E, Danthine S (2016) Grasshoppers as a food source? A review. Biotech Agron Soc Environ 20(S1):1–16.
Payne C, Evans J (2017) Nested houses: domestication dynamics of human-wasp relations in contemporary rural Japan. J Ethnobiol Ethnomed 13:13 https://doi.org/10.1186/s13002-017-0138-y
Peters W (2003) Integument. In: Dettner K, Peters W (eds) Lehrbuch der Entomologie. Elsevier, München, pp 183–195
Pimental D, Pimental M (2003) Sustainability of meat-based and plant-based diets and the environment. Am J Clin Nutr 78(suppl):660S–663S
Pimental D, Dritschilo W, Krummel J, Kutzman J (1975) Energy and land constraints in food protein production. Science 190:754–761
Pliner P, Hobden K (1992) Development of a scale to measure the trait of food neophobia in humans. Appetite 19:105–120
Pliner P, Mann N (2004) Influence of social norm and palatability of amount consumed and food choice. Appetite 42:227–237
Ramos-Elorduy de Conconi J, Pino-Moreno JM, Marquez-Mayaudon C et al (1984) Protein content of some edible insects in Mexico. J Ethnobiol 4:61–72

Reim H (1962) Die Insektennahrung der Australischen Ureinwohner. Akademie Verlag, Berlin
Righini N, Garber PA, Rothman JM (2015) The effects of plant nutritional chemistry on food selection of Mexican black howler monkeys (*Alouatta pigra*): the role of lipids. Am J Primatol. https://doi.org/10.1002/ajp.22524
Rozin P (1984) The acquisition of food habits and preferences. In: Matarazzo J, Weiss SM, Herd JA et al (eds) Behavioral health: a handbook of health enhancement. Wiley, New York, pp 590–607
Rozin P (2007a) Food choice: an introduction. In: Frewer LJ, Van Trip H (eds) Understanding consumers and food products. Woodhead Press, Cambridge, pp 3–29
Rozin P (2007b) How does culture affect choice of food? In: MacFie (ed) Consumer-led food product development. Woodhead Press, Cambridge, pp 66–80
Rozin P, Haidt J, McCauley CR (2008) Disgust. In: Lewis M, Haviland-Jones JM, Barrett LF (eds) Handbook of emotions. Guilford Press, New York, pp 757–776
Rumpold BA, Schlüter OK (2013) Nutritional composition and safety aspects of edible insects. Mol Nut. Food Re. 57, 802–23
Sabolová M, Adámková A, Kouřimska L, Chrpová D, Pánek J (2016) Minor lipophilic components in edible insects. Potravinárstvoi 10(1):400–406
Schabel HG (2010) Forest insects as food: a global review. In: Durst PB, Johnson DV, Leslie RN et al (eds) Forest insects as food: humans bite back, RAP public 2010/02. FAO, Bangkok, pp 37–64
Scholtz CH (1984) Useful insects. DeJager-HAUM Publishers, Pretoria
Scholtz MM, Van Ryssen JBJ, Meissner HH et al (2013) A South African perspective on livestock production in relation to greenhouse gases and water usage. S Afr J Anim Sci 43:247–254
Siegrist M, Hartmann C, Keller C (2013) Antecedents of food neophobia and its association with eating behaviour and food choices. Food Qual Prefer 30(2):293–298
Sun-Waterhouse D, Waterhouse GIN, You L, Zhang J, Liu Y, Ma L, Gao J, Dong Y (2016) Transforming inset biomass into consumer wellness food: a review. Food Res Int 89(1):129–151
Tan HSG, Fischer ARH, Tinchan P et al (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89
Teffo LS, Toms RB, Eloff JN (2007) Preliminary data on the nutritional composition of the edible stink-bug, *Encosternum delegorguei* Spinola, consumed in Limpopo province, South Africa. S Afr J Sci 103:434–436
Thornton PK (2010) Livestock production: recent trends, future prospects. Philos Trans R Soc Lond Ser B Biol Sci 365:2853–2867
Tuorila H (2007) Sensory perception as a basis for food acceptance and consumption. In: MacFie (ed) Consumer-led food product development. Woodhead Press, Cambridge, pp 34–65
Vabø M, Hansen H (2014) The relationship between food preferences and food choice: a theoretical discussion. Int J Bus Soc Sci 5:145–157
Van Huis A, Van Itterbeck J, Klunder H et al (2013) Edible insects: future prospects for food and feed. FAO, Rome
Ventura AK, Worobey J (2013) Early influence on the development of food preferences. Curr Biol 23(9):R401.R408
Westoby M (1974) An analysis of diet selection by large generalist herbivores. Am Nat 108:290–304
Yang L-F, Siriamornpun S, Li D (2006) Polyunsaturated fatty acid content of edible insects in Thailand. J Food Lipids 13:277–285
Ye X, Liu D, Hu C (2001) Some factors' effects on the solubility of protein from yellow mealworm (*Tenebrio molitor* L.) larvae. J Zhejiang Univ Sci B 2:436–438
Yhoung-Aree J (2010) Edible insects in Thailand: nutritional values and health concerns. In: Durst PB, Johnson DV, Leslie RN et al (eds) Edible forest insects: humans bite back. FAO, Bangkok, pp 201–216
Zagrobelny M, Dreon AL, Gomiero T et al (2009) Toxic moths: source of true delicacy. J Ethnobiol 29:64–76

Insects, The Next European Foodie Craze?

Rudy Caparros Megido, Éric Haubruge, and Frédéric Francis

Abstract Edible insects are systematically targeted as a major future food for European consumers but success in introducing entomophagy in Western society depends on factors governing consumers' attitudes towards insect-based products. Effectively, as for sushi in the 2000s, edible insects are considered as new food products in Europe and are deeply related to a fear or a reject feeling by consumers called "food neophobia". Consequently, several studies have been achieved to face the actual aversion of European consumers for insects. These studies principally tried to understand the insect-related neophobia, to highlight positive arguments for entomophagy development and also to test possible ways of integration of insects as food. The purpose of this chapter is to get an overview of the actual literature on edible insect acceptability in Europe to propose conceivable solutions for product development and new approaches for further studies.

1 Introduction

Edible insects are actually considered one of the major future foods in Europe. Insects have (1) high fecundity rates, with year-round breeding; (2) high conversion rates; (3) low environmental impact, due principally to low greenhouse gas emissions; (4) small breeding space requirements; and (5) in some species, the ability to recycle organic industrial and/or agricultural byproducts to feed livestock or humans (Defoliart 1995; DeFoliart 1997; Yen 2009; Bednárová et al. 2013; Rumpold and Schlüter 2013a, b; van Huis 2013; van Huis et al. 2013; Yi et al. 2013). If properly managed and consumed, edible insects are considered safe for human consumption and extremely beneficial when other classical food recommendation (e.g. food portion or balanced diet) are respected (Belluco et al. 2013; Sogari et al. 2017). Nevertheless, the main attitudes towards insects as food in Westernized societies

R. Caparros Megido (✉) · É. Haubruge · F. Francis
Entomologie Fonctionnelle et Evolutive, Gembloux Agro-Bio Tech, Université de Liège, Gembloux, Belgium
e-mail: r.caparros@ulg.ac.be

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_21

(i.e. a “term used very broadly to refer to a heritage of social norms, ethical values, traditional customs, belief systems, political systems, and specific artifacts and technologies that have some origin or association with Europe” or United States) are divided into two categories: curiosity and fear or disgust (Yen 2009). Curiosity generally only allows a fun appetizer with friends with few possibilities of additional purchase intentions. Nevertheless, fun trials could encourage people close to curious ones to “take the first step” and become acquainted with edible insects (Lensvelt and Steenbekkers 2014; Caparros Megido et al. 2016b). Because Western populations relate insects to health risks (Looy et al. 2013) and contamination (Deroy et al. 2015), most of the potential consumers related insect as food to negative feelings (Pascucci and de-Magristris 2013; van Huis 2013; Caparros Megido et al. 2014; Gmuer et al. 2016). Fear or disgust are the most cited negative feelings and are probably the biggest obstacle for entomophagy development. Culture defines and transmits information on the edibility of food ingredients and, in Europe, cultural rules define insects as non-edible or food to avoid (Mela 1999; van Itterbeeck 2008). The disgusting reaction in the Western world appears to be entirely acquired, arising in the period between the ages of 2 and 5 years (van Huis 2016). Parents learn through mere exposure and social learning which foods are appropriate to eat and how they are appropriately eaten and transmit to children these information (Tan et al. 2015). So the rejection of a food is not primarily based on the sensory properties of potential food, but rather on the knowledge of the nature or history of a potential food (van Huis 2016). This insect rejection, intrinsically linked to a disgust feeling, could be explained by a primitive and evolutionary survivor behaviour of omnivorous species (Asp 1999; Looy 2004). Since time immemorial, men have experimented new food, but in an extremely careful way to avoid any poisoning (Looy 2004). Consequently, the introduction of a new food ingredient in a culture generally induces this fear, or reject, called “food neophobia” (Haidt 2003; Looy 2004; Pliner and Salvy 2006; van Itterbeeck 2008). One of the main challenges to allow the use of edible insects in the Western world will be to find strategies that help consumers to overcome the neophobia related to their consumption. For more effective actions, entomophagy promoters need to gain insight on edible insect disgust. The following lines will describe the existing literature on understanding the edible insect disgust and rejection but also on the effectiveness of the current strategies.

2 Why Westerners Still Don’t Enjoy Insects as Food

Several factors responsible for triggering the aversion towards edible insects have been identified: from unique sensory properties and health safety concern (Kouřimská and Adámková 2016), to a barbaric practice only conceivable in the most desperate circumstance as well as the reminder of something alive (Martins and Pliner 2006; Schösler et al. 2012; Sogari et al. 2017). In fact, food acceptance strongly depends both on intrinsic factors related to sensory-affective reasons (e.g. sensory properties) and extrinsic ones related to cognitive (e.g. appearance), ideational (e.g. the nature and origin), societal (e.g. peer opinion) or safety (e.g. physical or psychological harm) aspects (Rozin and Fallon 1987; van Huis 2013; Tan et al. 2016a; Sogari et al. 2017). Fortunately for edible insect promotors, food preferences are not permanent and can change over time (van Huis 2013; Sogari et al. 2017). To increase the willingness to consume the novel animal food, there is a need to decrease individuals perceptions of the disgusting attributes (Martins and Pliner 2006). Information on proper use, positive taste or similarity to familiar food ("tastes like food X"), and exposure over time have been found to facilitate the acceptance of unfamiliar foods (Cardello et al. 1985; Pelchat and Pliner 1995; Tuorila et al. 1998; Hoek et al. 2013; Caparros Megido et al. 2016b). A first step to reduce food neophobia is to present the product in a meal context in due to increase familiarity with the product (Elzerman et al. 2011). To improve the willingness to eat novel food, a strong emphasis is usually placed on the use of familiar and liked flavours or preparations presenting the novel food in a way that looks and tastes familiar to consumer in order to create more positive expectations (Tuorila et al. 1998; Prescott et al. 2004; Tan et al. 2017). Effectively, food choice usually takes place within a range of familiar foods where taste satisfaction is a key driver for food choice (Prescott 1998; Tan et al. 2015).

2.1 A Question of Shape?

First stream of studies and presentation of insects as food was to propose entire edible insects associated with different kind of spices or other food ingredients (e.g. chocolate) to increase familiarity. Caparros et al. (2014) have shown that insects (crickets and mealworms) associated with known flavors (chocolate and paprika) and crispy textures were preferred by respondents in comparison with boiled or unseasoned insects. Insect appearance, principally for crickets with impressive legs and antennae, induced a neophobia among potential consumers. Associations of these two insects with vanilla were not liked by respondents supporting the importance of the appropriateness of edible insects by consumers as a usually liked food could also be dislike when presented in an appropriate context or situation. Following this assumption, Tan et al., (2015) studied the appropriateness of insect-based products or whether the food product matches the situation or context of consumption. In this study, naïve consumers (i.e. participants who never tasted insects) considered grasshoppers to be appropriately flavoured with salt or chili but not with chocolate. This result could be due to perceived mismatch between sensory properties of the products or mismatch with expectations of insects to be used as meat substitutes as the level of food appropriateness is known to be deeply related to safety aspects but also to ethical and healthy motivations (Tan et al. 2016a, b). Ideational motivations (sustainability of insect productions and the high protein level in edible insect) seem to have created expectations regarding the use of insects as meat substitutes or at least in preparations that are also appropriate to meat (Tan et al. 2016b). Westerner's evaluations were shown to be strongly dependent on the visibility of the insect ingredient (Hartmann et al. 2015; Gmuer et al. 2016). Several studies show that the invisible inclusion of insects in a preparation (i.e., pizza with insect protein or insect-based burgers) appear to trigger less aversion than the presentation of visible insects (Schösler et al. 2012; Pascucci and de-Magristris 2013; Caparros Megido et al. 2014; Lensvelt and Steenbekkers 2014; Tan et al. 2016b; Le Goff and Delarue 2017). Moreover, several studies emphasize the importance of socio-demographic characteristics, where young men have been shown to be more open to insects (Schösler et al. 2012; De Boer et al. 2013; Verbeke 2015; Barsics et al. 2016; Caparros Megido et al. 2016b) and could be considered to be possible early adopters of insects as food (House 2016; Tan et al. 2017).

2.2 What About the Disguised Ones?

As insects seems to be seen as a meat substitute and consumers are not ready to eat them in their whole shape, follow-up studies in the field have focused on the integration of powder or mixed insects in familiar food formulation. Schouteten et al. (2016) have shown that the overall liking of insect-based burger (31% of mealworms and 69% of vegetables) was similar to a plant-based burger but lower than a meat burger. An improvement of the product was suggested to propose a meat substitute with more meat-like sensory. Considering these previous results, Caparros et al. (2016b) facilitated a tasting session proposing hybrid insect-based burgers (half meat or half vegetable, half mealworms) to young consumers (students from 18 to 25 years old). This strategy seems to decrease the insect food neophobia since participants rated the insect-based burger's taste and appearance between a fully meat burger and a fully vegetable burger with a preference for the meat hybrid product. Familiarity with the entomophagy concept has been shown to positively influence the liking of insect-based products as already suggested by other studies (Mignon 2002; Tobler et al. 2011; Vanhonacker et al. 2013; Deroy et al. 2015). Information is of crucial importance given that the vast majority of European citizens, when presented with insect-based foods for the first time, will only rely on non-experimental sources of information (e.g. emotional memories, self-knowledge, or intuitive theories) to evaluate the product instead of the real insect sensory properties (Tan et al. 2016a). Communication on individual or societal benefits associated with edible insects have shown to increase intention to buy and eat insect-based products (Verneau et al. 2016) and the overall liking of insect-based product in women (Barsics et al. 2016) reinforcing the idea that information could impact the consumers' perceptions of entomophagy. To increase the familiarity of consumers with edible insects, several studies (Barsics et al. 2016; Caparros Megido et al. 2016b; Tan et al. 2016a) suggest to increase the number of tasting session as successive expositions are important for novel food acceptance (Pliner et al. 1993). After a first taste experience, consumers increasingly base their evaluations on their recall of past sensory experiences, rather than general information about the item

(Tan et al. 2016a). Barsics et al. (2016) have shown that even women, usually more neophobic than men, assigned higher score to insect-based bread appearance (identical to a whole wheat bread) when they had a prior entomophagy experience.

3 How to Build Long-Term Attractiveness?

People principally consider insects as a sustainable source of protein as the media promote them as high-protein food. This positive perception of the healthiness and sustainability of entomophagy seems to be sufficient as an initial motivation, and many consumers are willing to try despite their negativity (Tucker 2014; Tan et al. 2015, 2017; Sogari et al. 2017). Indeed, since familiarity with the idea of eating insects and the intention to reduce meat consumption are both expected to increase the likelihood of adopting insects as a meat substitute (Hartmann et al. 2015; Verbeke 2015), consumers who combine these characteristics might be the drivers for enabling such societal shifts. Their habits could impact other people by increasing familiarity and alleviating concerns. Nevertheless, as edible insect sensory appeal is in fact low, few consumers are willing to compromise on taste for other desired functional benefits which offer less immediate and tangible effects, and even the most motivated eaters remain unwilling to consume them on a regular basis (Tuorila and Cardello 2002; Tucker 2014; Tan et al. 2015, 2016b, 2017). Motivations for trial and regular consumption of insect-based foods are evidently very different and despite an appropriate product context seems to improve the willingness to buy insects regularly; repeated consumption is driven by more conventional considerations regarding food choice, such as the price, the taste, the low availability or the facility of preparation (House 2016; Sogari et al. 2017; Tan et al. 2017). Balzan et al. (2016) stated that the first step towards the acceptance of edible insects will be to provide more information about the modality of preparation and consumption as well as the availability of fresh products for restaurant or domestic use. Too many people believed that edible insects must be eaten crude, or alive, as it has been presented in some reality shows like in “Fear Factor” or “Koh Lanta” (Caparros Megido et al. 2016a). The education of consumers on edible insect preparation could be achieved through exposure via a cookbook or restaurant. Even if insect cookbooks are actually edited (Curry 2015), some of them contain words or adjectives like “bug” or “creepy crawly” and, actually, any traditional a cookbook proposes recipes with insect reinforcing the idea that edible insect is a very special and strange ingredient (Caparros Megido et al. 2016a). Concerning restaurants, only few of them propose insects on the menu in Europe and, of course, only in countries where edible insects are tolerated (Belgium, France, Netherlands and UK) (Stout 2016). The fact that edible insects are tolerated by authorities in only few countries in Europe could reinforce the idea that insects may not be edible or safe to eat. Moreover, it forced possible early adopters in non-tolerant countries to buy products by electronic commerce reducing the product appeal and potentially the first taste experience. A clear European legislative framework must be appropriately defined to allow insects to be a tangible food choice for consumers. Without this legislative framework, consumers cannot be reassured on food safety of current insect-based products which could be beneficial in the overall acceptance of edible insects. Sogari (2015) and Balzan et al. (2016) have also shown that the opinion of family and friends on the practice is important and might be critical in the integration of edible insects in countries with a strong culinary culture, such as Italy. Finally, to efficiently promote edible insect consumption in the Western world, we must keep in mind that food is a cultural and individual expression and that it is an essential part of our social relations (Caparros Megido et al. 2016a). For example, using words such as "mealworms" and "insects" could consistently link consumers with their negative feelings toward insects, likely helping to maintain a psychological barrier to edible insects. Further studies are needed to highlight the linguistic misunderstandings existing in the edible insect sector and to found terms that are easily understood and attractive (Wood and Looy 2014; Evans et al. 2015). The use of foreign words such as "*chapulines*" (i.e. crickets from the *Sphenarium* genus) could decrease neophobia by framing insect products as ethnic food (Wood and Looy 2014).

4 Conclusion

Edible insects are actually seen as future meat substitutes by some European consumers, and early adopters of entomophagy seem to be young men with an interest in healthy and sustainable food (Shelomi 2015; Verbeke 2015; House 2016). Further studies on the willingness to pay for and eat edible insects in this focus group as they could form the initial market for edible insects and influence general consumers by making the practice more common and attractive (Verbeke 2015; House 2016). Concerning general consumers, it seems that proper information on edible insect could impact their perceptions of entomophagy and that insect tasting sessions are important to decrease food neophobia, as they encourage people to "take the first step" and become acquainted with entomophagy (Lensvelt and Steenbekkers 2014; Barsics et al. 2016). It has been particularly effective for young women, who are generally more neophobic and less adventurous, as prior knowledge and experience with edible insects had shown to improve the appearance of a product with processed insects. Not surprisingly, marketing products containing processed insect ingredients seems to be initially more promising than marketing whole insects (Caparros Megido et al. 2016b; Gmuer et al. 2016; Schouteten et al. 2016). Marketing whole insects alone compared with incorporating whole insect into familiar food formulation seems to be preferred. Finally, practical and socio-cultural concerns (e.g. high price, low availability, lack of preparation knowledge or poor acceptance by peers) need to be overcome before regular consumption of edible insects is possible (Sogari et al. 2017; Tan et al. 2017). Through cookbooks, television shows or "bug banquets" (i.e. events where different insect preparations are proposed), entomophagy promoters must make insects delicious, to make them more appealing for the Western palate, with the help of restaurants or gastronomy labs, and finally make them a more festive and respected ingredient in European diets, similar to Crustaceans, their close relative. This will be achieved by bringing together ecology, psychology, gastronomy, social economics and knowledge from diverse traditional food cultures which consume edible insects, in order to make culturally appropriate the use of insects as a sustainable, nutritious and delicious ingredient (Halloran et al. 2015).

References

Asp EA (1999) Factors affecting food decisions made by individual consumers. Food Policy 24:287–295

Balzan S, Fasolato L, Maniero S, Novelli E (2016) Edible insects and young adults in a north-east Italian city an exploratory study. Br Food J 118:318–326. https://doi.org/10.1108/BFJ-04-2015-0156

Barsics F, Caparros Megido R, Blecker C et al (2016) Could new information influence attitudes to foods supplemented with edible insects? Br Food J 119(9):2027–2039

Bednárová M, Borkovcová M, Mlcek J et al (2013) Edible insects - species suitable for entomophagy under condition of Czech Republic. Acta U Agr et Silvi Mendelianae Brunensis 61:587–593

Belluco S, Losasso C, Maggioletti M et al (2013) Edible insects in a food safety and nutritional perspective: a critical review. Compr Rev Food Sci Food Saf 12:296–313. https://doi.org/10.1111/1541-4337.12014

Caparros Megido R, Sablon L, Geuens M et al (2014) Edible insects acceptance by belgian consumers: promising attitude for entomophagy development. J Sens Stud 29:14–20

Caparros Megido R, Alabi T, Haubruge E et al (2016a) Consommation d'insectes : des arguments santé à l'acceptation et au changement de comportement alimentaire. In: Le Gall P, Motte-Florac E (eds) Savoureux insectes De l'aliment traditionnel à l'innovation gastronomique. Presses universitaires de Rennes/Institut de Recherche pour le développement, Rennes

Caparros Megido R, Gierts C, Blecker C et al (2016b) Consumer acceptance of insect-based alternative meat products in western countries. Food Qual Prefer 52:237–243. https://doi.org/10.1016/j.foodqual.2016.05.004

Cardello AV, Maller O, Masor HB et al (1985) Role of consumer expectancies in the acceptance of novel foods. J Food Sci 50:1707–1718

Curry M (2015) Legged Lit: must-have edible insect books and cookbooks. In: Bug vivant gastronomy on six legs. http://bugvivant.com/6-legged-lit-6-must-have-edible-insect-books-and-cookbooks/. Accessed 25 Jan 2017

De Boer J, Schösler H, Boersema JJ (2013) Motivational differences in food orientation and the choice of snacks made from lentils, locusts, seaweed or "hybrid" meat. Food Qual Prefer 28:32–35

Defoliart GR (1995) Edible insects as minilivestock. Biodivers Conserv 4:306–321

DeFoliart GR (1997) An overview of the role of edible insects in preserving biodiversity. Ecol Food Nutr 36:109–132

Deroy O, Reade B, Spence C (2015) The insectivore's dilemma, and how to take the west out of it. Food Qual Prefer 44:44–55. https://doi.org/10.1016/j.foodqual.2015.02.007

Elzerman JE, Hoek AC, van Boekel MAJS, Luning PA (2011) Consumer acceptance and appropriateness of meat substitutes in a meal context. Food Qual Prefer 22:233–240

Evans J, Alemu MH, Flore R et al (2015) "Entomophagy": an evolving terminology in need of review. J Insects Food Feed 1:293–305. https://doi.org/10.3920/JIFF2015.0074

Gmuer A, Nuessli Guth J, Hartmann C, Siegrist M (2016) Effects of the degree of processing of insect ingredients in snacks on expected emotional experiences and willingness to eat. Food Qual Prefer 54:117–127
Haidt J (2003) The moral emotions. In: Davidson RJ, Scherer KR, Goldsmith HH (eds) Handbook of affective sciences. Oxford University Press, Oxford, pp 852–870
Halloran A, Münke C, Vantomme P et al (2015) Broadening insect gastronomy. In: Sloan P, Legrand W, Hindley C (eds) The Routledge handbook of sustainable food and gastronomy. Routledge, Oxford, pp 199–205
Hartmann C, Shi J, Giusto A, Siegrist M (2015) The psychology of eating insects: a cross-cultural comparison between Germany and China. Food Qual Prefer 44:148–156. https://doi.org/10.1016/j.foodqual.2015.04.013
Hoek AC, Elzerman JE, Hageman R et al (2013) Are meat substitutes liked better over time? A repeated in-home use test with meat substitutes or meat in meals. Food Qual Prefer 28:253–263
House J (2016) Consumer acceptance of insect-based foods in the Netherlands: academic and commercial implications. Appetite 107:47–58. https://doi.org/10.1016/j.appet.2016.07.023
Kouřimská L, Adámková A (2016) Nutritional and sensory quality of edible insects. NFS J 4:22–26. https://doi.org/10.1016/j.nfs.2016.07.001
Le Goff G, Delarue J (2017) Non-verbal evaluation of acceptance of insect-based products using a simple and holistic analysis of facial expressions. Food Qual Prefer 56:285–293. https://doi.org/10.1016/j.foodqual.2016.01.008
Lensvelt EJ, Steenbekkers LP (2014) Exploring consumer acceptance of Entomophagy: a survey and experiment in Australia and the Netherlands. Ecol Food Nutr 53:543–561. https://doi.org/10.1080/03670244.2013.879865
Looy H (2004) Embodied and embedded morality: divinity, identity, and disgust. Zygon 39:219–235
Looy H, Dunkel FV, Wood JR (2013) How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric Hum Values 31(1):131–141
Martins Y, Pliner P (2006) "Ugh! That's disgusting!": identification of the characteristics of foods underlying rejections based on disgust. Appetite 46:75–85. https://doi.org/10.1016/j.appet.2005.09.001
Mela DJ (1999) Food choice and intake: the human factor. Proc Nutr Soc 58:513–521. https://doi.org/10.1017/S0029665199000683
Mignon J (2002) L'entomophagie : une question de culture ? Tropicultura 20:15–155
Pascucci S, de-Magristris T (2013) Information bias condemning radical food innovators? The case of insect-based products in the Netherlands. Int Food Agribusiness Manage Rev 16:1–16
Pelchat ML, Pliner P (1995) "Try it. You"ll like it.' Effects of information on willlingness to try novel foods. Appetite 24:153–165
Pliner P, Salvy S-J (2006) Food neophobia in humans. In: Shepherd R, Raats M (eds) The psychology of food choice. CABI, London, pp 75–92
Pliner P, Pelchat M, Grabski M (1993) Reduction of neophobia in humans by exposure to novel foods. Appetite 20:111–123
Prescott J (1998) Comparisons of taste perceptions and preferences of Japanese and Australian consumers: overview and implications for cross-cultural sensory research. Food Qual Prefer 9:393–402
Prescott J, Young O, Zhang S, Cummings T (2004) Effects of added "flavour principles" on liking and familiarity of a sheepmeat product: a comparison of Singaporean and New Zealand consumers. Food Qual Prefer 15:187–194. https://doi.org/10.1016/S0950-3293(03)00057-0
Rozin P, Fallon AE (1987) A perspective on disgust. Psychol Rev 94:23–41
Rumpold BA, Schlüter OK (2013a) Nutritional composition and safety aspects of edible insects. Mol Nutr Food Res 57:802–823
Rumpold BA, Schlüter OK (2013b) Potential and challenges of insects as an innovative source for food and feed production. Innovative Food Sci Emerg Technol 17:1–11
Schösler H, Boer JD, Boersema JJ (2012) Can we cut out the meat of the dish? Constructing consumer-oriented pathways towards meat substitution. Appetite 58:39–47

Schouteten JJ, De Steur H, De Pelsmaeker S et al (2016) Emotional and sensory profiling of insect-, plant- and meat-based burgers under blind, expected and informed conditions. Food Qual Prefer 52:27–31. https://doi.org/10.1016/j.foodqual.2016.03.011

Shelomi M (2015) Why we still don't eat insects: assessing entomophagy promotion through a diffusion of innovations framework. Trends Food Sci Technol. https://doi.org/10.1016/j.tifs.2015.06.008

Sogari G (2015) Entomophagy and Italian consumers: an exploratory analysis. Prog Nutr 17:311–316

Sogari G, Menozzi D, Mora C (2017) Exploring young foodies' knowledge and attitude regarding entomophagy: a qualitative study in Italy. Int J Gastr Food Sci 7:16–19

Stout J (2016) Ban them or boost them? The EU's struggle with edible insects. In: Bugsfeed. http://www.bugsfeed.com/the_eu_struggle_with_edible_insects. Accessed 25 Jan 2017

Tan HSG, Fischer ARH, Tinchan P et al (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89. https://doi.org/10.1016/j.foodqual.2015.01.013

Tan HSG, Fischer ARH, van Trijp HCM, Stieger M (2016a) Tasty but nasty? Exploring the role of sensory-liking and food appropriateness in the willingness to eat unusual novel foods like insects. Food Qual Prefer 48:293–302. https://doi.org/10.1016/j.foodqual.2015.11.001

Tan HSG, van den Berg E, Stieger M (2016b) The influence of product preparation, familiarity and individual traits on the consumer acceptance of insects as food. Food Qual Prefer 52:222–231. https://doi.org/10.1016/j.foodqual.2016.05.003

Tan HSG, Verbaan YT, Stieger M (2017) How will better products improve the sensory-liking and willingness to buy insect-based foods? Food Res Int 92:95–105. https://doi.org/10.1016/j.foodres.2016.12.021

Tobler C, Visschers VHM, Siegrist M (2011) Eating green. Consumers' willingness to adopt ecological food consumption behaviors. Appetite 57:674–682. https://doi.org/10.1016/j.appet.2011.08.010

Tucker CA (2014) The significance of sensory appeal for reduced meat consumption. Appetite 81:168–179

Tuorila H, Cardello AV (2002) Consumer responses to an off-flavor in juice in the presence of specific health claims. Food Qual Prefer 13:561–569. https://doi.org/10.1016/S0950-3293(01)00076-3

Tuorila HM, Meiselman HL, Cardello AV, Lesher LL (1998) Effect of expectations and the definition of product category on the acceptance of unfamiliar foods. Food Qual Prefer 9:421–430

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

van Huis A (2016) Edible insects are the future? Proc Nutr Soc 75:294–305. https://doi.org/10.1017/S0029665116000069

van Huis A, van Itterbeeck J, Klunder HC et al (2013) Edible insects: future prospects for food and feed security. Food and Agriculture Organization of The United Nations, Rome

van Itterbeeck J (2008) Entomophagy and the west: barriers and possibilities, ecological advantages, and ethical desirability. Dissertation, University of Wageningen

Vanhonacker F, Van Loo EJ, Gellynck X, Verbeke W (2013) Flemish consumer attitudes towards more sustainable food choices. Appetite 62:7. https://doi.org/10.1016/j.appet.2012.11.003

Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a western society. Food Qual Prefer 39:147–155. https://doi.org/10.1016/j.foodqual.2014.07.008

Verneau F, La Barbera F, Kolle S et al (2016) The effect of communication and implicit associations on consuming insects: an experiment in Denmark and Italy. Appetite 106:30–36. https://doi.org/10.1016/j.appet.2016.02.006

Wood JR, Looy H (2014) Hospitality and edible insects: welcoming the world to our table. Paper presented at the conference Eating innovation: the art, culture, science & business of entomophagy, montréal space for life, Montréal, 26–28 August 2014

Yen A (2009) Edible insects: traditional knowledge or western phobia? Entomol Res 39:289–298

Yi L, Lakemond CMM, Sagis LMC et al (2013) Extraction and characterisation of protein fractions from five insect species. Food Chem 141:3341–3348

Kenyan Consumers' Experience of Using Edible Insects as Food and Their Preferences for Selected Insect-Based Food Products

Mohammed Hussen Alemu and Søren Bøye Olsen

Abstract In this chapter we present information in relation to consumption, purchase experience, consumption frequency and peoples' perceptions of how others see edible insects as food in Kenya. Two edible insects, namely termites (*Macrotermes subhyalinus*) and mealworms (*Tenebrio molitor*) were considered to study Kenyan consumers' willingness-to-pay (WTP) for termite-based food products (TBFPs) and their reactions to using mealworms as food. In the research, whole and processed insects were considered in order to examine consumers' WTP for TBFPs in different products formats and contexts. The data originates from a choice experiment survey conducted between December 2014 and January 2015 involving a sample of Kenyan consumers. To ensure a high degree of representativeness of the sample, five counties including Siaya, Kisumu, Nairobi, Kakamega and Machakos were chosen due to their diversity with regard to insect consumption traditions, regions (rural or urban), and socio-demographic factors (age, education and gender). In total, 611 consumers who were either household heads or spouses were randomly sampled in the survey areas and interviewed using face-to-face interviews.

1 Consumption and Purchase Experience of Edible Insects in General

In the survey, respondents were asked whether they had tasted edible insects or meals containing edible insects. If affirmative, they were asked about the insect species, consumption frequency, purchase experience, and reasons for eating or not eating edible insects as food. Around 80% of the respondents said they had previously tasted insects. The most popular edible insects for consumption are termites and lake flies followed by grasshoppers, locusts, black and white ants, and crickets as reported in Alemu et al. (2017a). More than half (55%) of the respondents had

M. H. Alemu (✉) · S. B. Olsen
University of Copenhagen, Department of Food and Resource Economics, Frederiksberg C, Denmark

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_22

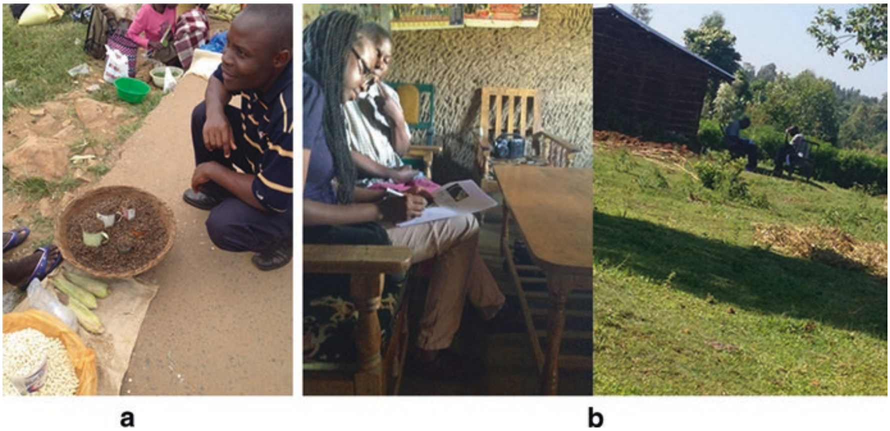


Fig. 1 (**a**) Roasted termites sold at the street market of Kakamega town in Kenya, (**b**) House to house interviewing of respondents (Photo – Mohammed H Alemu)

Table 1 Consumption frequency of insect-based food products

More than once in a month	7.5%
Once in a year	27.5%
More than once in a year	40.5%
Don't know	24.5%

previously bought food products made from edible insects, mainly whole termites dried and roasted (see Fig. 1), in local markets.

They had typically paid amounts ranging from 5 Kenyan Shillings[1] (KShs) to 200 KShs with an average price of 55 KShs. As shown in Table 1, while more than 25% of the respondents consume insect-based food products once a year or less, 40% of them do this more than once in a year. The proportion of respondents, who consume insect-based foods on a fairly regular basis, i.e. more than once every month, is only 7.5% in the sample. Hence, while consumption of edible insects would seem to be quite familiar to most Kenyans, it is far from considered an everyday food item.

Most respondents stated that they have tasted edible insects because of the following reasons: (1) "edible insects are traditionally eaten where I am living", (2) "edible insects are delicious and they are a good source of protein", and (3) "there are a lot of edible insects in my area and access is free", and (4) "other food products from meat are expensive and unavailable". Respondents who have never tasted edible insects or meals that contain edible insects stated: (1) "Edible insects are disgusting", (2) "Edible insects are dangerous for health", (3) "Eating edible insects would affect my social status", and (4) "It is culturally and religiously prohibited to eat edible insects in my area". The issue of the 'disgust' factor in relation to con-

[1] 1 US Dollar was exchanged with 90.50 KShs during the data collection period.

suming insects is often aligned with Western consumers (DeFoliart 1999; Huis 2013; Halloran et al. 2014; Looy et al. 2014; Deroy et al. 2015). Our results, however, suggest that this factor can also contribute to the rejection of insects as food by some people in Kenya.

2 Respondents' Perceptions of How Others See Edible Insects in General

Table 2 presents descriptive results concerning respondents' perceptions of how others perceive edible insects as food in Kenya. When asked to respond on a 5-point Likert scale ranging from very negative to very positive, around 65% of the respondents said that others in their household consider food products made from edible insects as positive or very positive. On the other hand, while 60% of them responded that others in their neighbourhood perceive food products made from edible insects positively to very positively, only 45% stated that the majority of people in Kenya have similar perceptions of such foods. One can see that the proportion of people, who perceive that others see edible insects as food positively to very positively, decreases as we go from a household level to a country level. When asked about their own immediate thoughts about food products made from edible insects, approximately 80% of the respondents stated that they perceived it positively or very positively.

It would be interesting to present the above results by comparing rural to urban areas as well as areas with insect consumption tradition to without. The results in Tables 3 and 4 show that the percentage proportion of consumers who perceive that others see edible insects as food positively to very positively decreases as we go from rural to urban areas, and from traditional insect consumption to non-traditional insect consumption areas. This decrease is very large when we only look at the percentage proportion of consumers who perceive that others see edible insects as food very positively.

Table 2 Kenyan consumers' perception of how others see edible insects (percentage of respondents)

	Very negative	Negative	Neither negative not positive	Positive	Very positive
How do you think others in your household see foods from edible insects?	6.1	12.6	15.1	39.4	26.8
How do you think the majority of people in your surroundings see foods from edible insects?	1.6	8.3	29.3	37.9	22.9
How do you think the majority of people in Kenya see foods from edible insects?	0.7	8.2	44.1	36.7	10.3
What is your immediate thought about foods from edible insects?	5.1	7.9	9.0	39.4	38.6

Table 3 Kenyan consumers' perception of how others see edible insects (% of respondents by urban and rural distribution)

	Very negative		Negative		Neither negative nor positive		Positive		Very positive	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
How do you think others in your household see foods from edible insects?	2.3	3.8	5.7	7.0	4.3	10.8	24.3	14.7	23.4	3.7
How do you think the majority of people in your surroundings see foods from edible insects?	0.8	0.8	2.9	5.2	7.9	21.4	26.8	11.1	21.8	1.3
How do you think the majority of people in Kenya see foods from edible insects?	0.3	0.3	3.9	4.3	23.9	20.1	23.7	12.9	8.1	2.5
What is your immediate thought about foods from edible insects?	1.9	3.1	4.4	3.4	2.8	6.2	20.6	18.8	30.4	8.4

3 Consumer Responses to Mealworms as Food

In another part of the survey, respondents were asked a closed "yes or no" question on whether they would accept to eat mealworm-based food products (see Table 5). A pictorial representation shown in Fig. 2 was used to describe mealworms since the focus group interviews indicated that most consumers were not familiar with these insects. The mealworms are presented with Ugali,[2] which is usually served with collard greens (best known by its local name as *Sukuma wiki*).

Only 20% stated that they would be willing to accept whole roasted mealworms as food. On the other hand, the ground form of mealworms (mealworms powder) appeared to be more acceptable as the proportion of respondents willing to accept it as food was slightly higher at 30%. Somewhat surprisingly, only around 5% of the consumers in the survey said they would be willing to buy Ugali flour mixed with mealworm powder even if the price was discounted compared to regular Ugali flour without mealworm powder.

These descriptive results generally indicate that most Kenyan consumers would be reluctant to consume mealworms as food. This is also supported by the result that only one third of the consumers would accept mealworms as food if the government

[2] Ugali is considered one of the main staple food products in Kenya. It is prepared as dough or porridge from sorghum or maize flour.

Table 4 Kenyan consumers' perception of how others see edible insects (% of respondents by insect consumption tradition)

	Very negative		Negative		Neither negative nor positive		Positive		Very positive	
	Trad	NTrad	Trad	NTrad	Trad	NTrad	Trad	NTrad	Trad	NTrad
How do you think others in your household see foods from edible insects?	1.6	4.4	5.4	7.2	5.1	10.0	24.1	15.4	23.7	3.1
How do you think the majority of people in your surroundings see foods from edible insects?	0.5	1.1	2.8	5.4	8.7	20.6	26.4	11.6	21.6	1.3
How do you think the majority of people in Kenya see foods from edible insects?	0.2	0.5	4.4	3.8	22.3	21.8	24.7	11.9	8.2	2.2
What is your immediate thought about foods from edible insects?	1.6	3.4	4.3	3.6	3.6	5.4	19.8	19.6	30.6	8.1

Trad; Consumers from traditional insect consuming communities, NTrad; Consumers from non-traditional insect consuming communities

Table 5 Consumer responses to mealworm-based food products

	Yes	No
Would you accept to eat mealworms roasted?	20%	80%
Would you accept to eat mealworm powder mixed in Ugali?	30%	70%
Would you buy Ugali flour mixed with mealworm powder if the price is cheaper than Ugali flour without mealworm powder?	5%	95%
Would you accept to eat foods from mealworms if the government introduces awareness creation programs to promote the consumption of mealworms?	30%	70%

Fig. 2 (**a**) Ugali made with mealworm powder, (**b**) Roasted mealworms (Photo: Mohammed H Alemu)

introduces awareness creation programs to promote the consumption of edible insects in general and mealworms in particular. When asked the reasons for not being willing to accept mealworms as food, most consumers stated that they considered mealworms disgusting because their appearance is not appealing and that they were not familiar with mealworms.

4 Consumers' Willingness-to-Pay for Termite-Based Food Products

In this section, consumers' WTP (willingness-to-pay) estimates for TBFPs (termite based food products) are presented. The TBFPs considered in the survey were whole termites fried and salted, and a processed form of termites, namely termite powder. The products are assumed to be served with Ugali; the whole termites can be served beside it whereas the powder form is mixed into the Ugali. Hence, the powder form is thus not visible, as can be seen in Fig. 3. As indicated above, Ugali is usually served with collard greens in Kenya as shown in the figure below. The calculation of the WTP is based on empirical results obtained from a latent class model. This model enables identification of segments of respondents with distinctly different preference structures (Boxall and Adamowicz 2002). Respondents within a segment are likely to have similar preferences. The probability of respondents being allocated to a segment can be determined based on their attitudes and demographic characteristics. We refer the reader to Alemu et al. (2017a) for further information on the data analysis procedure as well as on issues related to the choice of the different TBFPs.

The WTP results reported in Tables 7 and 8 reflect how much the consumers are willing to pay for a TBFP characterized by different attributes. Each attribute is explained by different levels where one of them serves as a reference level, thus the interpretation of the WTP estimates is made relative to this level. Therefore, they can be considered as marginal WTP estimates. The attributes of the TBFPs and their levels are shown in Table 6.

The latent class modelling procedure reveals four distinct segments of preferences in our sample. Considering the WTP estimates for whole termites fried and salted in Table 7, more than 45% of the consumers in segment 1 are likely to pay

a b

Fig. 3 (**a**) Ugali made with termite powder (Alemu et al. 2017a), (**b**) Whole termites fried (Alemu et al. 2017a)

Table 6 Attributes and their levels

Attribute definition	Attribute levels (name)
Nutritional value of the TBFPs may differ depending on the production method (e.g. the feed quality they are fed on); processing methods (e.g. drying, boiling, and frying) and storage methods (e.g. whether stored appropriately in cool and dry conditions).	Low (reference level) Average High
Food safety control indicates to what extent the TBFPs are controlled for their safety. *Standard* represents the traditional way of preparing termites for food, i.e. drying, boiling, and frying. *High* represents the termites are fed based on a controlled feed quality and living conditions. Proper processing and handling strategies are applied to prevent hygienic and re-contamination problems during food preparation processes. The products are packed. *Very high* denotes that in addition to high food safety control, the products are inspected for specific food safety issues by the Kenyan bureau of standards to ensure that they are safe.	Standard (reference level) High Very high
Shopping location indicates whether the TBFPs are available in local or street markets, kiosks, or bigger supermarkets.	Local market (reference level) Kiosks Supermarkets
Recommendation represents whether people get recommendations from various sources to consume foods from TBFPs.	None (reference level) Friends and relatives Media Official
Price is the cost of 200 g of the TBFPs in Kenyan Shillings (KShs)	50 60 70 85 105 120

Alemu et al. (2017a)

more for the products with average to high nutritional value, very high food safety control level and recommended by officials. The highest WTP (275 KShs) is found in this segment for high nutritional value followed by 110 KShs for a very high food safety control. The second segment of consumers, which contains 30% of the them, have positive WTP for whole termites with average nutritional value, high food safety control level, and recommended by peers and officials. Unlike consumers in the first segment who put a negative marginal WTP on kiosks, those in the second segment are positively willing to pay a marginal price of 50 KShs to buy whole termites in kiosks. 14% of the Consumers are grouped into the third segment. They are willing to incur a cost of 100 KShs for whole termites with high nutritional value relative to the one with low nutritional value. The WTP estimates for segment 4 are not reported as they do not meet the conventional levels of statistical significance. The segment weighted WTP results may be used to rank the factors based on their relative magnitude of the marginal WTP estimates. Accordingly, high nutritional

Table 7 Marginal willingness to pay for whole termite fried and salted (KShs)

	Segment 1	Segment 2	Segment 3	Segment 4	Segment weighted WTP
High nutritional value	272.8 (37.1)***	−55.4 (6.8)***	100 (25.8)**	–	127.6
Average nutritional value	49.6 (12.2)**	24.2 (4.6)***	89.6 (28.9)	–	30.8
Very high food safety control	107.6 (21.2)***	−21.2 (5.4)**	−48 (22.0)	–	45.2
High food safety control	−47 (16.7)	41.4 (5.9)***	51 (23.5)	–	12.4
Official recommendation	82.4 (19.6)**	30.6 (6.6)**	74.6 (32.8)	–	48.6
Media recommendation	59.4 (18.2)	−31 (6.3)**	−107.8 (39.8)	–	−9.4
Peers recommendation	−70.2 (19.7)*	40.8 (5.9)***	33 (26.6)	–	−21.4
Sold in supermarkets	−39.6 (12.4)	4.8 (4.2)	1.4 (17.4)	–	–
Sold in kiosks	−74.4 (14.2)***	50.2 (4.7)***	30.8 (19.3)	–	−20.4
Segment probability	0.478	0.301	0.137	0.085	1

Standard errors in parenthesis
'*' denotes statistical significance at 10% level, '**' denotes statistical significance at 5% level, and '***' denotes statistical significance at 1% level

Table 8 Marginal willingness to pay for termite powder (KShs)

	Segment 1	Segment 2	Segment 3	Segment 4	Segment weighted WTP
High nutritional value	127.8 (8.1)***	−21.4 (25.6)	–	55.8 (17.9)	85.4
Average nutritional value	48.2 (5.5)***	−416.4 (93.1)**	–	50.4 (13.2)*	−16.6
Very high food safety control	81.8 (7.6)***	−8 (29.7)	–	−84.6 (19.5)**	46.2
High food safety control	21.6 (5.1)**	−328.4 (76.1)**	–	65.2 (15.1)**	−21.4
Official recommendation	36 (8.3)**	−136 (40.9)*	–	158.6 (28.7)***	22.4
Media recommendation	95.2 (9.9)***	−499.6 (126.2)**	–	−114.6 (26.9)**	−12.4
Peers recommendation	28 (5.3)***	−199.8 (48.3)**	–	57.6 (16.5)*	−1.2
Sold in supermarkets	−14.8 (5.1)	103 (28.0)*	–	66.4 (17.5)*	20
Sold in kiosks	34.6 (5.9)***	104.6 (40.7)	–	−67.8 (18.1)*	16.4
Segment probability	0.668	0.129	0.102	0.101	1

Standard errors in parenthesis
'*' denotes statistical significance at 10% level, '**' denotes statistical significance at 5% level, and '***' denotes statistical significance at 1% level

value comes first followed by official recommendation. Very high food safety control, average nutritional value, and high food safety control can be listed as third, fourth, and fifth factor.

The WTP results for termite powder are presented in Table 8. The first segment comprises of more than 65% of consumers. These consumers are willing to pay more for recommendation (i.e. official, media and peers) as opposed to 13% of consumers in the second segment, who are found to have decreasing WTP for termite powder unless it is sold in supermarkets. Nutritional value (both high and average), and food safety control level (both high and very high) are important for consumers in the first segment as they are positively willing to buy termite powder characterized by these factors. The WTP for the nutritional value goes up to approximately 130 KShs and up to 80 KShs for a very high food safety control of the termite powder. While consumers in the second segment would pay approximately 100 KShs for termite powder sold in supermarkets and kiosks, the WTP for the latter is found to be statistically insignificant. This means selling the products in kiosks is less likely to affect these consumers' WTP for such products. Groups of consumers in the fourth class are willing to sacrifice around 160 KShs and 60 KShs for termite powder recommended by official and peers', respectively. Similar to whole termites, around 10% of consumers have WTP which are not statistically significant, thus not reported in Table 8.

5 Discussion and Conclusion

The results compiled here indicate that Kenyan consumers are familiar with edible insects as food since people traditionally consume some types of insects especially in western parts of the country. Most consumers have tasted termites and some of them have bought roasted or fried termites in local street markets. While termites appear to be quite popular in Kenya, the opposite is the case for mealworms. Only few people show positive willingness to accept mealworm-based food products. There is some suggestions in the literature that education and awareness creation might improve the acceptance of insect-based foods (e.g. Looy et al. 2014; Looy and Wood 2015; Vantomme 2015; Yen 2015). However, most consumers in our survey reacted negatively to mealworms as food although they were instructed to imagine a scenario in which their government designs awareness creation programs to promote the use of mealworms as food in Kenya. This suggests that even if education is important for promoting insect-based foods, the type of the insect can still be a determining factor for consumer acceptance.

Promoting edible insects as food may benefit from information on peoples' perception of how others see edible insects as food since this would help to understand the overall consumers' attitude toward such foods. As discussed in Alemu et al. (2017a); Looy et al. (2014); Tan et al. (2015); and Hartmann et al. (2015) consumers' attitudes and preferences will determine the success of introducing insect-based food products, and advancing our understanding of consumer behaviour is relevant for efforts to promote edible insects as food. Information on others' perception of insect-based foods can also be related to the importance of social factors and peers influence for consumer acceptance of new food products (see Salazar et al. 2013; and Woods and Hayes 2012 for related literature). Most respondents in our survey generally think that others in their households and neighbourhoods see foods from edible insects positively to very positively. This can facilitate social interaction in a manner that increases consumer acceptance of insects as food as people have positive perception about others' attitudes towards insects as food.

The results concerning consumers' WTP imply that a large proportion of Kenyans are likely to buy insect-based foods. Households with higher number of members value higher nutritional value the highest for whole termites fried and salted, suggesting that these consumers may find these insects to be a viable source of protein. Consumers who are willing to pay the highest amount for the high nutritional value of termite powder are likely to originate from areas where insect eating is traditionally popular and they practice farming and fishing as their main occupation.

While various factors would determine the WTP of consumers for the insect products to nutritional value, food safety control, recommendation from other sources, shopping location as well as the cost of the products seem to be important for consumers. It is noteworthy that some of these factors influence consumers' WTPs in different ways. For instance, nutritional value and food safety control level positively drive consumers' WTP for both whole termites as well as termite powder. Nevertheless, recommendation from officials, media and peers as well shopping location in terms of supermarkets and kiosks tend to increase most consumers' WTP more for termite powder than for whole termites fried. As noted in Alemu et al. (2017a), the tendency to prefer and to be willing to pay more for the processed termite which is sold in conventional outlets would signal the food safety concern consumers may have if these products were sold in local markets. While it is easy to recognize that the whole version of an edible insect is in fact that insect, this is not possible for the processed powder version. Thus, the consumer cannot visibly confirm the food product but simply has to trust the producer that the powder is actually made from the edible insects as claimed. This can also be related to the fact that termite powder is a new product for Kenyan consumers as they are familiar with whole termites only. Some studies such as McFadden and Train (1996) and Hoeffler (2003) show that consumers may find it difficult to form preferences for new products because they are not familiar with them and they may need more time and information to make appropriate choice decisions. Specifically, Verbeke (2015); Hartmann and Siegrist (2016) and Verneau et al. (2016) concluded that familiarity with insects as food determines consumers' intention to consume insect-based food products. While these studies utilized data from western consumers, their overall messages are in line with the implication of our results.

In conclusion, Kenyan consumers' responses to insects as food are generally positive despite the specific type of insects having important bearings on acceptability. Edible insects have the potential to play an important role in achieving food security and reducing micronutrient deficiency in Kenya (Alemu et al. 2017a, b). This is related to the fact that the idea of consuming insects is not new for Kenyans since most people have tasted termites and other insects before, which can help the success of mass-production and introduction of insect-based food products in Kenya. This in return would call for the introduction of regulatory and quality control schemes that require great cooperation between insect commercialization companies and government agencies (Alemu et al. 2017b). In addition to commercialization, farming insects can be important because this would increase food supplies at household level and generate cash incomes as well as create employment opportunities for the poor in rural Kenya. Similar conclusions are reported in other studies such as Kelemu et al. (2015), Ayieko et al. (2016), and Halloran et al. (2016).

Acknowledgements The authors would like to acknowledge the generous financial support from the Danish International Development Agency (DANIDA), Ministry of Foreign affairs of Denmark through the *GREEiNSECT* project (www.greeinsect.ku.dk). We thank the editors for their constructive comments.

References

Alemu MH, Olsen SB, Vedel SE, Pambo KO, Owino VO (2017a) Combining product attributes with recommendation and shopping location attributes to assess consumer preferences for insect-based food products. Food Qual Prefer 55:45–57

Alemu MH, Olsen SB, Vedel SE, Kinyuru J, Pambo KO (2017b) Can insects increase food security in developing countries? An analysis of Kenyan consumer preferences and demand for cricket flour buns. Food Sec 9:471–484

Ayieko MA, Ogola HJ, Ayieko IA (2016) Introducing rearing crickets (gryllids) at household levels: adoption, processing and nutritional values. J Insects Food Feed 2(3):203–211

Boxall, P, Adamowicz, W (2002) Understanding Heterogeneous Preferences in Random Utility Models: A Latent Class Approach. Environ Resour Econ 23:421–446

DeFoliart GR (1999) INSECTS AS FOOD: why the western attitude is important. Annu Rev Entomol 44(1):21–50

Deroy O, Reade B, Spence C (2015) The insectivore's dilemma, and how to take the west out of it. Food Qual Prefer 44:44–55

Halloran A, Muenke C, Vantomme P, Huis A v (2014) Insects in the human food chain: global status and opportunities. Food Chain 4(2):103–118

Halloran A, Roos N, Flore R, Hanboonsong Y (2016) The development of the edible cricket industry in Thailand. J Insects Food Feed 2(2):91–100

Hartmann C, Siegrist M (2016) Becoming an insectivore: results of an experiment. Food Qual Prefer 51:118–122

Hartmann C, Shi J, Giusto A, Siegrist M (2015) The psychology of eating insects: a cross-cultural comparison between Germany and China. Food Qual Prefer 44(0):148–156

Hoeffler S (2003) Measuring preferences for really new products. J Marketing Res 40(4):406–420

Huis A v (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58(1):563–583

Kelemu S, Niassy S, Torto B, Fiaboe K, Affognon H, Tonnang H, Maniania NK, Ekesi S (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insects Food Feed 1(2):103–119

Looy H, Wood JR (2015) Imagination, hospitality, and affection: the unique legacy of food insects? Anim Front 5:8–13

Looy H, Dunkel F, Wood J (2014) How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric Hum Values 31(1):131–141

McFadden, DL, Train, KE (1996) Consumers' Evaluation of New Products: Learning from Self and Others. J Political Econ 104:683–703

Salazar HA, Oerlemans L, van Stroe-Biezen S (2013) Social influence on sustainable consumption: evidence from a behavioural experiment. Int J Consum Stud 37(2):172–180

Tan HSG, Fischer ARH, Tinchan P, Stieger M, Steenbekkers LPA, van Trijp HCM (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42(0):78–89

Vantomme P (2015) Way forward to bring insects in the human food chain. J Insects Food Feed 1(2):121–129

Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a western society. Food Qual Prefer 39(0):147–155

Verneau F, La Barbera F, Kolle S, Amato M, Del Giudice T, Grunert K (2016) The effect of communication and implicit associations on consuming insects: an experiment in Denmark and Italy. Appetite 106:30–36

Wood W, Hayes T (2012) Social Influence on consumer decisions: motives, modes, and consequences. J Consum Psychol 22(3):324–328

Yen AL (2015) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insects Food Feed 1(1):33–55

Consumer Acceptance of Insects as Food: Integrating Psychological and Socio-cultural Perspectives

Hui Shan Grace Tan and Jonas House

Abstract Although interest in the use of insects as food is growing in Europe and the US (the "West"), Western insect consumption remains far from widespread. Western resistance to entomophagy is often contrasted with the favourable position of edible insects in other regions, but little scholarship thus far has engaged with the question of why this difference exists. Drawing mainly on two qualitative studies, we compare the factors affecting insect consumption in contexts where it is both established (northeast Thailand) and where it is not (the Netherlands). We argue that the integration of different disciplinary perspectives elucidates the complexity of consumer acceptance, which goes beyond simple "willingness to eat" insects. Our research shows that the positioning of insects as an appreciated, regularly consumed food is the result of the intersection of a broad range of psychological, socio-cultural, practical and contextual factors. In addition to the commonly discussed psychological factors, regular insect consumption is determined by previous experience, culinary knowledge, wider cultural associations, established routines of food provisioning and eating, and the availability, price, form and taste of products. We suggest both demand-side factors (changing consumer perceptions) and supply-side factors (creating tasty, usable, distinctive and accessible products) are equally important to gaining consumer acceptance. We also emphasise that initial motivations to eat insects and repeated consumption are different things, and that there is a need to distinguish between the two in future scholarly and commercial efforts.

H. S. G. Tan (✉)
Food Quality and Design, Wageningen University, Wageningen, The Netherlands

J. House
Sociology of Consumption and Households, Wageningen University, Wageningen, The Netherlands

Department of Geography, University of Sheffield, Sheffield, United Kingdom

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_23

1 Introduction

Despite growing interest in entomophagy, few Western consumers appear willing to adopt insects into their existing diets (Tucker 2014; Verbeke 2015) and Western insect consumption remains low (Shelomi 2015). Western resistance to entomophagy greatly contrasts with various Asian, Latin American and African cultures where a large variety of insect species are highly regarded for their excellent taste (Ramos-Elorduy 1997; Nonaka 2009; Hanboonsong 2010; Raffles 2010). Yet little is understood about the factors that contribute to these differences. Consumer studies on Western acceptance of insects as food often focus on consumer negativity and how to overcome it (Hartmann et al. 2015; Verbeke 2015; Baker et al. 2016; Gmuer et al. 2016), but have so far given little attention to how the repeated consumption of this culturally unfamiliar food could be achieved in the West.

The principal focus of this chapter is to consider and compare the factors affecting consumer acceptance (and rejection) of insects as food in cultural settings where certain insect species are a regular part of diets (i.e. northeast Thailand) and where insects have yet to gain acceptance (i.e. the Netherlands). By examining differences in consumer perceptions and rationales, and taking into consideration the different social, contextual and practical factors affecting the consumption of food within the specific cultures, we aim to provide a better understanding of the complex challenges involved in achieving acceptance of a culturally unfamiliar food. We argue that in the context of encouraging dietary change to improve the sustainability of food systems, consumer acceptance should not only consider people's willingness to eat insects, but should also consider the broader contextual factors that influence food consumption.

Studies in places where insects are regularly consumed (e.g. Ramos-Elorduy 1997; Nonaka 2009; Raffles 2010; Halloran et al. 2016b; Riggi et al. 2016) hint at the richness, complexity and contingency of food supply and consumption practices involving insects. They illustrate the role not only of individual attitudes and motivations but also a wealth of external factors in the positioning of insects as a desirable food source. For example, Ramos-Elorduy's (1997) work in Mexico explains the diversity of relevant factors affecting the inclusion of insects in diets. These include "habits, traditions, cosmology and food sources" (1997: 348), the latter of which is heavily determined by the availability of particular foods in particular regions. She considers the influence of migration patterns, the labour market, and national infrastructure on the diets of rural populations, which contribute to the general social context of insect consumption. More specifically, established practices of identifying, collecting and preparing food insects are discussed, as are prominent discursive or psychological framings of insects: for example, as "little animals" and as "clean, healthy and savoury" (1997: 352).

Studies on Western consumers, on the other hand, typically investigate how psychological factors (e.g. food neophobia, disgust sensitivity, risk perceptions) influence people's reported general or initial willingness to eat insects (Lensvelt and Steenbekkers 2014; Hartmann et al. 2015; Ruby et al. 2015; Verneau et al. 2016).

However, given widespread unfamiliarity with the taste and use of insects as food in the West, as well as the very low availability of insect food products, these evaluations are largely confined to explaining the different facets of current consumer negativity towards the *idea* of insect consumption. They provide little insight into how insects could fit in and around established eating practices in the context of "real life" food consumption (cf. Ramos-Elorduy 1997; Raffles 2010).

According to Martins and Pliner (2005), an individual's willingness to eat an unfamiliar food is dependent very much on their level of interest and disgust, whereas once familiarity with the food is gained, the anticipated quality of the taste experience becomes a strong driver. Further, sociological accounts of food and eating (e.g. Halkier and Jensen 2011; Warde 2016) illustrate that food consumption is shaped not just by these individual motivations and drivers, but also by a diverse range of social, geographical and practical factors. These include the location and material conditions of domestic residence, the presence of co-inhabitants, routines of work, leisure and care, access to financial and other resources (such as personal transport), the manner in which one typically obtains and prepares food, and so on. Access to food itself is of course also crucial in determining its consumption, and limited availability is suggested to be inhibiting uptake of insect-based foods in the West (Shelomi 2015; House 2016). As noted above, these kind of factors tend to be acknowledged within work on regions in which insects are traditionally consumed (e.g. Riggi et al. 2016), but are mostly absent from current investigations of Western uptake of insects as food.

A better understanding of the psychological and sociological factors underlying consumer acceptance of insects is needed to indicate salient areas for academic, commercial and policy attention. Here we will discuss and integrate the findings of two qualitative studies (Tan et al. 2015; House 2016) that examined cultures where insects are a relatively normalised foodstuff (i.e. consumed by many) and where insects are not generally used as food (i.e. consumed by few). In the study by Tan et al. (2015), focus group interviews were conducted in two cultural contexts where entomophagy is generally practiced (i.e. Isaan region in Thailand) and not practiced (i.e. the Netherlands), to investigate the consumer perceptions and rationales regarding insects as food amongst individuals who differed in experience with eating insects. The study by House (2016) extends this research further. House (2016) conducted semi-structured interviews with 33 consumers of insect-based foods in the Netherlands to examine the social and contextual factors involved when willing early adopters endeavour to incorporate insects into their diet. In the discussion below, previously unpublished data from ongoing research by House is also drawn upon. This data is from a series of follow-up interviews with 20 of House's (2016) original participants, conducted in a second wave of research that began 6 months after the initial data collection was completed. These primarily focused on whether or not people had continued to eat insect-based foods and their reasons for it.

Together the above studies provided several new insights into the challenges of integrating a culturally unfamiliar food into existing diets, which are discussed thematically in the following sections.

2 Study Findings

2.1 *Knowledge and Experiences with Insects as Food*

Thailand is well known for the consumption and appreciation of numerous edible insect species (>150 species) (Hanboonsong 2010). Commonly consumed insect species in Thailand include crickets, bamboo caterpillars, weaver ants, grasshoppers, palm weevils and giant water bugs, although their popularity varies greatly according to the region of Thailand. Particularly in the northern, northeastern, and southern regions of Thailand, the consumption of insects is supported by a combination of wild harvesting and farming of certain species (e.g. crickets). During seasons of abundance, raw and cooked insects are readily available at various markets and street stands. The cross-cultural focus groups of Tan et al. (2015) were conducted in the city of Sakon Nakhon in northeastern Thailand, although some participants were from other regions where the availability and consumption of insects may differ. It was found that despite insects being a common food in Sakon Nakhon, not everyone there consumed insects, and not everyone who did would be willing to eat just any species.

Thais who are regular consumers of insects ("eaters") demonstrated rich and extensive knowledge and experiences regarding the usage and consumption of various available species and preparations (Tan et al. 2015). They were familiar with the tastes of the various species that they consume, and how they are best prepared to enhance their qualities as well as the taste of the dish that they are incorporated within. For instance, Thai eaters were aware that insects with a hard exoskeleton (e.g. grasshoppers) should be roasted or fried (and not boiled) to enable them to be easily chewed down, and that the strong flavours of the giant water bug can be used to enhance the flavour of chilli sauce. Even Thais who did not eat insects ("non-eaters") still possessed some knowledge regarding the use of insects as food that they had gained through indirect experiences with other locals and at the markets. These were mainly locals who had either grown up in other regions of Thailand where insects are not common as food, or were from families who did not regularly consume insects. Apart from eating insects, they did not appear to be much different from Thai eaters in terms of their food preferences. For these "non-eaters", possessing knowledge and indirect experiences did not translate into a willingness to eat, where past bad experiences or the absence of direct experience from a young age were often named as reasons for not eating.

Such knowledge and experience was lacking amongst the Dutch participants in Tan et al.'s (2015) study. Unlike the Thai context, insects have only recently been introduced in the Netherlands as human food. Since around 2008, grasshoppers, crickets, mealworms and buffalo worms have been produced in the Netherlands for human consumption, and have mainly been available as freeze-dried whole insects. Their sale has chiefly been limited to online vendors and other independent food retailers, although some branches of larger supermarket chains in the country have stocked the products since late 2014 (RTV Rijnmond 2014). A range of insect-based convenience foods (including burgers, nuggets and schnitzel) has also been available in stores of a Dutch supermarket chain for the same period. These products do not appear to have been a huge commercial success (House 2016).

The cross-cultural study (Tan et al. 2015) showed that even if Dutch consumers have tasted insects before, they possessed little knowledge about the tastes of the different insect species and how they should be prepared. House found further that for those consumers who had tried to cook the freeze-dried whole insects available in the Netherlands, lack of culinary knowledge hindered repeat consumption. The few participants who had attempted to cook whole insects had purchased the insects after happening to find them for sale in shops or at food events, and generally reported that experimentation with insect cooking had been repeated either infrequently or not at all. Participants mostly guessed their most suitable culinary application based on taste expectations. For instance, a participant occasionally ate buffalo worms on top of toast with brie and honey as she associated their taste with nuts, but emphasized that beyond this she did not really know what to do with them. Another participant made a mealworm curry following an online recipe, but never made it again, as she considered the size and texture of the insects inappropriate for that meal type.

House (2016) also investigated the food consumption practices of consumers of a range of insect-based convenience foods that were evidently designed in the manner of conventional vegetarian products. These foods (e.g. burger patties) did not require the acquisition of new culinary skills or the reconfiguration of cooking practices. In this respect, the need for knowledge regarding how to prepare and cook insects was circumvented. However, while the inclusion of insects as an invisible ingredient within familiar food products helps to remove certain barriers to insect consumption – resistance to visible insects, and/or lack of knowledge regarding their preparation – it does not necessarily guarantee repeated consumption and the integration of insect-based food into diets. Tan et al. (2015) showed that even if the insects were not visible or perceivable within the product, consumers' uneasiness upon knowing they are eating a strange and unfamiliar food still is a major psychological barrier. House (2016) further suggested that the invisible integration of insects into familiar foods may remove the appeal of selecting an insect-based product rather than one containing a different protein source, which may be cheaper, tastier, or easier to acquire.

2.2 Interest, Motivations, and Repeat Consumption

In the study by Tan et al. (2015), rich positive experiences of the Thai consumers of insects resulted in taste being a strong motive for insect consumption. Thai eaters spoke extensively about how delicious and enjoyable various species are when prepared and consumed in specific manners, and spoke of how insects could be obtained in seasons of abundance. In contrast, for those who were unfamiliar with eating insects (i.e. Thai non-eaters and Dutch participants), reported interest and motivations to eat tended to revolve around curiosity regarding the novelty of insects and accounts of the perceived benefits of consuming them, as well as the various contextual and practical concerns that need to be addressed. It was observed that several of the Dutch participants were particularly interested in new tastes and meat alternatives when discussing their general food preferences, where individual inclinations regarding new foods seemed to influence curiosity levels.

The Dutch participants – whether or not they had tasted insects before – reported motivations to eat that were largely dominated by what they had learned about insects' nutritional and environmental value. However, this did not mean that they were ready to eat insects, and they expressed various criteria that should be satisfied (e.g. price, availability, taste, appearance) in order for insects to be considered for repeated consumption. Decisions to eat the insect-based products during the research sessions revealed that amidst high interest in this novel food many were willing to try the products despite their negativity, but expressed little intention to consume them regularly. In the study by House (2016), it was shown that the above practical and product-based criteria became particularly important amongst the willing Dutch consumers when repeated consumption was considered.

Among House's (2016) Dutch participants, a range of conventional factors affected repeat consumption of insect-based foods. One was price, which was around 35% higher than comparable plant-based products which (as is explained below) were the main frame of reference. Others were taste (evaluated by only a third of participants as appealing), and the products' limited availability in the Netherlands (1–3 products in one supermarket chain or 17.4% of supermarkets – see Distrifood 2016). Another key factor was the degree to which the insect foods "fit" with established eating practices, with a poor fit resulting in significantly impaired consumption. This included the consumption frequency of vegetarian convenience foods and level of adherence to a traditional Dutch meal format. It also encompassed broader factors (e.g. shop locations, household routines) affecting food provisioning.

Both Tan et al. (2015) and House (2016) thus highlight that the initial willingness to eat insects could be driven very much by the novelty and perceived benefits of insect consumption, but that this interest alone is generally insufficient to encourage repeat purchase, which is affected by a range of conventional factors associated with food consumption.

2.3 Perceptions, Preferences and Product Development

In Tan et al.'s (2015) study, exposure to certain species and preparations resulted in common preferences towards the available species in each cultural context. The available species were more familiar and evoked fewer negative responses. As such, due to differences in availability, species preferences differed for the Thai and the Dutch. Yet familiarity per se was not the reason for liking certain species.

The cross-cultural study showed that familiar species and products were evaluated based on both positive and negative past experiences, and these past experiences influenced the interpretation and evaluation of insect foods (see Alba and Hutchinson 1987; Dick et al. 1990; Banović et al. 2012). For the Thai, the consumption of certain species of insects was discontinued after previous negative experiences, whereas positive experiences led to repeat consumption and the accumulation of rich experiences and strong preferences towards the species and its preparations. For instance, Thai participants who had eaten species such as the giant water bug spoke of how its flavour greatly enhanced the taste of chilli sauce, whereas some others did not like the pungent flavour of the insect. Those who had never tasted it before often mentioned its ugly appearance and resemblance to cockroaches, which were associations that made the species relatively less attractive as food.

By comparing the responses towards familiar and unfamiliar insect species, Tan et al. (2015) showed that when a species had never been tasted before, its visual features and species-related associations influenced the reported liking and willingness to eat. The associations evoked with the unfamiliar insect species depended on the learned associations within the cultural context and the way the food is prepared and presented. For instance, according to the Thai participants in Tan et al.'s (2015) study, the appearance of mealworms strongly resembled maggots that decompose carcasses and they were therefore extremely unappealing as food, whereas this association was not present amongst the Dutch participants. Also, incorporating whole mealworms within a muffin evoked associations of decay for both Dutch and Thai participants, which was not an issue if invisibly incorporated within a cookie. This indicates that insect-based foods could be designed to suppress these negative species-related associations. However, it was also important to the Dutch participants that insect-based products fit their motivations to use insects as a sustainable alternative to meat. Hiding insects within sweet products (e.g. chocolate, cookies) was perceived by some to be meaningless if their goal is to be more environmentally-friendly in their food choices, and therefore not worth regular consumption even if the product looks acceptable.

In the study by House (2016), most consumers of the insect-based convenience foods did use them in place of meat. However, the foods were mostly seen as comparable to vegetarian "meat substitute" products rather than meat (such as beef, pork or chicken) itself – indeed, 33% of the group self-identified as vegetarian. This positioning raised some difficulties, with meat-eating participants remarking that unless insect foods tasted as good as meat they would not be considered as a direct replacement. The general understanding that the insect foods were broadly equivalent to vegetarian products seems to have been affected by the very similar design of insect-based and vegetarian products and their placement next to each other in stores. As such it appears that insects are not currently considered as a direct replacement for pigs, cows, and chickens, but rather as one option among many meat substitute products. This categorisation may be problematic, a point which we discuss in greater depth below.

3 Discussion and Implications

Yen (2009) argues that “[t]here is a major attitudinal barrier to the use of insects as human food in western societies” (2009: 294). However, our qualitative studies show that negative attitudes or perceptions are only one side of the story. This is for two main reasons. Firstly, there is evidence that even if negative perceptions are overcome and tasty products are made, people remain uncomfortable about the idea of knowingly eating insects. Secondly, even if negative perceptions are overcome, there are still a host of other reasons affecting whether or not insects are actually eaten.

Consequently there is a need to better address the intersecting psychological, social, contextual and practical factors that affect insect consumption. An illustrative comparison can be drawn between Thai and Dutch willing consumers of insects (Tan et al. 2015; House 2016). For the Thai consumers (Tan et al. 2015), their willing consumption of insects was facilitated by the long-term availability of a supply of tasty insects in local markets (see also Halloran et al. 2016b), as well as the existence of established cooking and eating practices with insects which they had been exposed to and involved in. For Dutch consumers (House 2016), their willingness and ability to consume insects was inhibited by the intermittent supply of relatively expensive insect foods whose taste was generally not rated highly, as well as the absence of established culinary practices involving insects. The lack of clarity about the appropriate culinary use of European-bred food insects is reflected in a Dutch cookbook on the subject (see House 2015). Lack of established cooking practices involving insects also appears to have contributed to their being invisibly incorporated into existing food types such as convenience foods. This may help reduce the barriers to trial (e.g. Hartmann et al. 2015; Gmuer et al. 2016) but does not necessarily lead to acceptance, as people may still perceive the insect-containing product to be inappropriate for human consumption (Tan et al. 2016a) or inferior in quality to the original product (Tan et al. 2016b, 2017). The use of insects as an imperceptible ingredient may also diminish the positive reasons for selecting an insect-based product, rather than a cheaper or tastier non-insect equivalent (House 2016).

In a social and cultural context where food insects are difficult to obtain, relatively expensive, and lacking a markedly pleasurable taste, even consumers who are highly motivated to eat insects are unlikely to maintain consumption. Shelomi (2015) has suggested that achieving Western acceptance of insects as food may be less of a demand-side question (i.e. changing consumer perceptions regarding insects) and more a supply-side one: “changes in values”, he observes, “are often supply driven, and not the other way around” (2015: 315). Indeed, the more widespread acceptance of insects as food in the Sakon Nakhon region is evidently associated with their taste and local availability (Tan et al. 2015), suggesting – in line with Shelomi (2015) – that the ready availability of various edible species in particular regions is a precondition for their more favourable cultural and culinary position. Yet the rejection of insects as food by the Thai non-eaters (Tan et al. 2015) also indicates that addressing the supply-side issues alone is insufficient to establish consumption, if no efforts are made to change the prevailing negative attitudes or lack of interest in adopting a new food into the diet. Adequate supply is a necessary but not sufficient condition for acceptance of insects as food (cf. Riggi et al. 2016).

Our research has highlighted some dilemmas and challenges. One is that there is the issue of growing Western interest in eating insects but with little translation into regular consumption. Interest stemmed from insects' novelty and benefits as a sustainable and nutritious alternative to conventional meat, but the negative perceptions regarding insect-based foods, and the lack of supply of food insects that are tasty, easily available and readily affordable, precludes their consumption even among the willing. Further studies suggest that these negative perceptions are difficult to change even with taste exposure, particularly due to the cultural inappropriateness of insects as food in Western cultures (Tan et al. 2015, 2016a), where insects are not merely regarded as unfamiliar food, but not food at all (Looy et al. 2014). Yet even if these psychological factors can be overcome, other contextual and practical factors (Shelomi 2015; Tan et al. 2017) remain barriers to regular consumption.

Another dilemma is that the primary Western motivation to introduce insects as food as an environmentally-friendly meat alternative created expectations regarding the use of insects as a meat substitute. However, positioning insects in this way raises its own challenges. Our research (Tan et al. 2015; House 2016) shows that Dutch willing consumers of insects tend to frame insects in general terms as a meat substitute, but also that the current crop of insect-based foods in the Benelux region are positioned both psychologically and practically as closer to a vegetarian product than a novel form of meat (House 2016). Such positioning is influenced by the specific facets of production, distribution and retail undergirding the form and availability of insect foods in the Benelux region, and is not simply indicative of a homogeneous "Western attitude" (e.g. DeFoliart 1999; Looy et al. 2014). Nevertheless three general points can be tentatively extrapolated from House's (2016) findings.

Firstly, insect food's feasibility as a direct alternative to conventional animal protein appears to rely on it being evaluated as having an equivalent level of tastiness to meat. It is thus, as Verbeke (2015) notes, unlikely to directly replace meat any time soon. Secondly, insect food's positioning as a vegetarian-style meat substitute means that it is subjected to the same criteria as the latter foods, meaning that without significant advantages over non-insect alternatives in price, taste and availability, it is unlikely to be selected often, if at all. As research on organic and GM food suggests, people's support or rejection of foods on environmental or ethical grounds may have less of a bearing on consumption than more mundane factors such as price (Clarke et al. 2008; Sleenhoff and Osseweijer 2013). Thirdly, the positioning of insects as broadly equivalent to vegetarian foods appears to lead to their consumption by vegetarians. Some of these vegetarians were environmentally motivated, and thus avoided only certain animal species; others were motivated by animal welfare considerations, but considered insects beyond the bounds of ethical concern (see House forthcoming). While a consumer's replacement of beef with an insect product may have a net environmental benefit (Oonincx and De Boer 2012), if consumers who currently only eat plant-based diets start to also consume animal protein in the form of insects, could this make the environmental impact of their diet worse?

It has been suggested that insects' credentials as an environmentally-friendly alternative to meat are dependent on various contingent factors, such as the species used, the sustainability of the feed used to rear them, and the energy requirements involved in their production (Lundy and Parrella 2015; Halloran et al. 2016a). This raises the possibility that for Westerners (who rely on either Western-farmed or imported insects), exclusively plant-based diets may be better for the environment than plant-based diets which also incorporate insects. Although more research in this area is needed, there is a strong case for arguing that insects do not represent a "magic bullet" to improve the sustainability of all diets.

Our results lead us to emphasise two key messages for those working in the field, which are relevant for those working in academia, business, and policy alike.

The first of these is that there is a clear need to consider not only psychological and product factors, but also the social and contextual factors affecting the acceptance of insects as food. Acceptance, in our view, does not just mean trying an insect product once, but rather making it an accepted and integrated part of one's diet. We wish to clarify that the psychological, product, social and contextual factors we discuss are inextricably linked: analytic priority can naturally be given to particular factors for the purposes of explanation or empirical research, but this must not be at the expense of the acknowledgment of the others. We have attempted to show how the specific conditions of insect consumption (e.g. product attributes, availability, social and contextual positioning) are related to insects' use in food and to the reported preferences and evaluations of insect species in relation to food applications. Each affects the other; they are "mutually constitutive". Future research should thus not only focus on hypothetical willingness to consume, but should also engage with the socio-cultural context of food consumption and psychological factors related to the food experience, in order to provide a fuller picture of consumer acceptance.

Our second key message is that initial motivations to eat insect-based foods and the factors affecting repeat consumption are different things, and that there is a need to distinguish between the two. For those who are relatively new to the idea of eating insects, reported motivations tend to be curiosity or rationalised considerations like insects' perceived healthiness or sustainability (Tan et al. 2015; House 2016), whereas factors affecting repeat consumption include conventional considerations like price, taste, availability, knowing how to cook with them, and the established practices of food provisioning and consumption into which insects must fit. These are important determinants of food consumption which evidently affect other, more established foods as well, and should be given greater attention when introducing a culturally unfamiliar food.

Rational arguments focusing on novelty, health, and sustainability may be a good way to raise Western interest in eating insects, but without attention to the more conventional factors affecting repeat consumption of food more generally, this initial interest is unlikely to result in sustained consumption. We suggest that there is a need to not only raise interest and improve consumer perceptions through exposure, but to also address the supply-side factors and create a conducive environment to guide, encourage and facilitate the consumption of insects in a manner that fulfils the primary environmental goals of introducing insects in the West.

Consumer-side measures to raise general awareness and culinary knowledge could involve promotional activities by prominent "tastemakers" such as chefs, gastronomic workshops, and cookbooks. Supply-side measures to facilitate Western insect consumption could include the development of relevant policy or legislation, the establishment of adequate rearing, production and distribution infrastructure to produce insects at scale, and attention to product development that takes into account factors that will encourage repeat – rather than one-time – consumption. We emphasise, however, that "insects" are not a homogeneous category (Evans et al. 2015). Thus while efforts to promote insects may provoke interest in particular species or modes of preparation (e.g. Halloran et al. 2015), these species must be readily available if they are to become a feasible food option.

Acknowledgements Jonas House's research received funding from the Economic and Social Research Council, grant number ES/J500215/1. Hui Shan Grace Tan's research received funding from the IP/OP Customized Nutrition programme financed by Wageningen University & Research Centre.

References

Alba JW, Hutchinson JW (1987) Dimensions of consumer expertise. J Consum Res 13:411–454

Baker MA, Shin JT, Kim YW (2016) An exploration and investigation of edible insect consumption: the impacts of image and description on risk perceptions and purchase intent. Psychol Mark 33:94–112

Banović M, Fontes MA, Barreira MM, Grunert KG (2012) Impact of product familiarity on beef quality perception. Agribusiness 28:157–172

Clarke N, Cloke P, Barnett C, Malpass A (2008) The spaces and ethics of organic food. J Rural Stud 24:219–230

DeFoliart GR (1999) Insects as food: why the western attitude is important. Annu Rev Entomol 44:21–50

Dick A, Chakravarti D, Biehal G (1990) Memory-based inferences during consumer choice. J Consum Res 17:82–93

Distrifood (2016) Marktaandelen. In: Distrifood. http://www.distrifood.nl/service/marktaandelen. Accessed 22 Nov 2016

Evans J, Alemu MH, Flore R et al (2015) "Entomophagy": an evolving term in need of review. J Insects Food Feed 1:293–305

Gmuer A, Guth JN, Hartmann C, Siegrist M (2016) Effects of the degree of processing of insect ingredients in snacks on expected emotional experiences and willingness to eat. Food Qual Prefer 54:117–127

Halkier B, Jensen I (2011) Methodological challenges in using practice theory in consumption research. Examples from a study on handling nutritional contestations of food consumption. J Consum Cult 11:101–123

Halloran A, Flore R, Mercier C (2015) Notes from the "Insects in a gastronomic context" workshop in Bangkok, Thailand. J Insects Food Feed 1:241–243

Halloran A, Roos N, Eilenberg J, Cerutti A, Bruun S (2016a) Life cycle assessment of edible insects for food protein: a review. Agron Sustain Dev 36:57

Halloran A, Roos N, Flore R, Hanboonsong Y (2016b) The development of the edible cricket industry in Thailand. J Insects Food Feed 2:91–100

Hanboonsong Y (2010) Edible insects and associated food habits in Thailand. In: Durst PB, Johnson DV, Leslie RN, Shono K (eds) Edible forest insects: humans bite back. Food and Agricultural Organization of the United Nations, Bangkok, pp 173–182

Hartmann C, Shi J, Giusto A, Siegrist M (2015) The psychology of eating insects: a cross-cultural comparison between Germany and China. Food Qual Prefer 44:148–156

House J (2015) Books in review: the insect cookbook: food for a sustainable planet. Gastronomica 15:85–86

House J (2016) Consumer acceptance of insect-based foods in the Netherlands: academic and commercial implications. Appetite 107:47–58

House J (forthcoming) Are insects animals? The ethical position of insects in Dutch vegetarian diets. In: Linzey A, Linzey C (eds) Ethical vegetarianism and veganism. Routledge, London

Lensvelt EJ, Steenbekkers LPA (2014) Exploring consumer acceptance of entomophagy: a survey and experiment in Australia and the Netherlands. Ecol Food Nutr 53:543–561

Looy H, Dunkel FV, Wood JR (2014) How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric Hum Values 31:131–141

Lundy ME, Parrella MP (2015) Crickets are not a free lunch: protein capture from scalable organic side-streams via high-density populations of Acheta domesticus. PLoS One 10:e0118785

Martins Y, Pliner P (2005) Human food choices: An examination of the factors underlying acceptance/rejection of novel and familiar animal and nonanimal foods. Appetite 45(3):214–224

Nonaka K (2009) Feasting on insects. Entomol Res 39:304–312

Oonincx DG, de Boer IJ (2012) Environmental impact of the production of mealworms as a protein source for humans – a life cycle assessment. PLoS One 7:e51145

Raffles H (2010) Insectopedia. Pantheon Books, New York

Ramos-Elorduy BJ (1997) The importance of edible insects in the nutrition and economy of people of the rural areas of Mexico. Ecol Food Nutr 36:347–366

Riggi LG, Veronesi M, Goergen G, MacFarlane C, Verspoor RL (2016) Observations of entomophagy across Benin – practices and potentials. Food Secur 8:139–149

RTV Rijnmond (2014) Eetbare insecten in schappen supermarkt R'dam. In: RTV Rijnmond. http://www.rijnmond.nl/nieuws/118017/Eetbare-insecten-in-schappen-supermarkt-R-dam. Accessed 22 Nov 2016

Ruby MB, Rozin P, Chan C (2015) Determinants of willingness to eat insects in the USA and India. J Insects Food Feed 1:215–225

Shelomi M (2015) Why we still don't eat insects: assessing entomophagy promotion through a diffusion of innovations framework. Trends Food Sci Technol 45:311–318

Sleenhoff S, Osseweijer P (2013) Consumer choice: linking consumer intentions to actual purchase of GM labeled food products. GM Crops Food 4:166–171

Tan HSG, Fischer ARH, Tinchan P, Stieger M, Steenbekkers LPA, van Trijp HCM (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89

Tan HSG, Fischer ARH, van Trijp HCM, Stieger M (2016a) Tasty but nasty? Exploring the role of sensory-liking and food appropriateness in the willingness to eat unusual novel foods like insects. Food Qual Prefer 48:293–302

Tan HSG, van den Berg E, Stieger M (2016b) The influence of product preparation, familiarity and individual traits on the consumer acceptance of insects as food. Food Qual Prefer 52:222–231

Tan HSG, Verbaan YT, Stieger M (2017) How do better products improve the sensory-liking and willingness to buy insect-based foods? Food Res Int 92:95–105

Tucker CA (2014) The significance of sensory appeal for reduced meat consumption. Appetite 81:168–179

Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Qual Prefer 39:147–155

Verneau F, La Barbera F, Kolle S, Amato M, Del Giudice T, Grunert K (2016) The effect of communication and implicit associations on consuming insects: an experiment in Denmark and Italy. Appetite 106:30–36

Warde A (2016) The practice of eating. Polity Press, Cambridge

Yen AL (2009) Edible insects: traditional knowledge or western phobia? Entomol Res 39:289–298

Customer Acceptance, Barriers, and Preferences in the U.S.

Melissa A. Baker, Jungyoung Tiffany Shin, and Young Wook Kim

Abstract While insect consumption occurs and is accepted throughout the world, acceptance and adoption of entomophagy is particularly low in the United States. This chapter investigates the current state of customer acceptance of edible insects in the United States, potential market segments, barriers to insect consumption, and marketing initiatives to minimize risk and maximize benefits. For customer acceptance in the U.S., cultural factors play a large role in low adoption. Potential market segments include consumers that are health conscious, environmentally conscious, and seek exciting, new, and novel food experiences. The major barriers to insect consumption include cultural barriers, food neophobia, perceptions of disgust, and risk factors. Therefore, it is important to investigate the marketing initiatives that can best minimize risk and maximize benefits such as image and description marketing, education, and public policy.

1 Introduction

As noted in previous chapters, insects are highly valued as food in many cultures but have only recently gained interest in the U.S. as a sustainable protein alternative to reduce the environmental impact of traditional meat production (Tan et al. 2016). While human insect consumption occurs throughout Asia, South America, and Africa, most Westerners, especially those in the U.S., do not consume insects and

M. A. Baker (✉)
Department of Hospitality and Tourism Management, Isenberg School of Management, University of Massachusetts, Amherst, MA, USA
e-mail: mbaker@isenberg.umass.edu

J. T. Shin
Conrad N. Hilton College of Hotel & Restaurant Management, University of Houston, Houston, TX, USA

Y. W. Kim
Korean Edible Insect Laboratory Knowledge Cooperative Association, Seoul, Republic of Korea

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_24

have a strong aversion to the idea of insects as food. It is therefore critical to investigate customers' acceptance and barriers of consuming insects from an entomological, psychological, and marketing perspective (Baker et al. 2016).

Despite the benefits as previously discussed in this book, consumer acceptance in the United States is one of the largest barriers to the adoption of insects as food. Therefore, this chapter will discuss current customer acceptance in the U.S., potential target market segments, barriers to insect consumption, and marketing initiatives to minimize risk and increase benefits.

2 Customer Acceptance in the U.S.

2.1 Current State of Edible Insects in the U.S.

Eating insects occurs globally, but consuming insects is viewed with disgust in the U.S. (Baker et al. 2016). Nevertheless, there are food product companies and food-service establishments within the U.S. that are breaking down the boundaries with customers, creating food products and restaurant dishes that not only entice customers to try edible insects, but hope to create repeat purchasing from customers. Primarily, edible insects in the U.S. is still a niche market, yet U.S. companies are increasingly served by food startups which are gaining in brand recognition (Menozzi et al. 2017). Some of the most prominent edible insect food companies selling in the U.S. include Exo (cricket energy bars), Chapul (cricket energy bars), Chirps (chips made with cricket powder), and Bitty (cricket-baked flour goods). Chapul, which Mark Cuban invested in on the popular U.S. TV show Shark Tank, is on track for revenues of over one million dollars, in part due to a distribution deal with UNFI, a national distributor of health-food products (Eha 2016). Mark Cuban also invested in Chirps on a 2017 episode of Shark Tank further committing to the sustainable and alternative protein market in the U.S. While there are some companies that use other of the over 1900 kinds of edible insects, the most successful companies the in the U.S. predominantly use crickets. For the U.S. consumer, "crickets are the gateway bug" (Eating Insects Detroit 2016). In the U.S., crickets are the most commonly farmed, there are several companies that make excellent cricket flour, and are the most mild, less feared edible insect (Hay 2016). According to Exo's Chief of Communications, their research finds that crickets provoked the most minor fear response in comparison to other edible insects. Hiding crickets within foods essentially minimizes the fear, and eliminates the initial taboo of eating insects, hence why many consider crickets America's "Gateway Bug" (Hay 2016) (Fig. 1).

In more urban markets, such as New York, Washington, D.C., and San Francisco, restaurants are serving grasshopper tacos and silkworm soup (Taylor 2015). Edible insects are also being served to college students in the form of roasted crickets at the

Fig. 1 U.S. edible insect food products

University of Connecticut through one of the university's food trucks (Diluna 2015). In addition, companies such as Little Herds are also spearheading educational efforts regarding the future of edible insects. In May of 2016, the first international, interdisciplinary conference on the topic of insects as food and feed was held in Detroit, Michigan. There, experts from anthropology, entomology, food science, marketing, and entrepreneurs gathered to discuss the benefits and barriers to insect consumption, focusing specifically on the U.S. market (Eating Insects Detroit 2016). The conference was an overwhelming success and brought to light many of the factors that need to be addressed to improve customer acceptance of edible insect consumption. Such factors are further discussed within this chapter including potential market segments barriers to acceptance, and marketing initiatives to increase acceptance.

2.2 *Cultural Factors*

Culture, anthropology, history, and geography all play a role in the way different regions perceive products (Baker et al. 2016). One of the largest factors barring the widespread acceptance of insects as food is culture (Halloran et al. 2014). In the U.S., human consumption of insects is infrequent and often viewed as culturally inappropriate (Van Huis 2013). The vast majority of U.S. consumers react with disgust at the prospect of ingesting creatures that are more familiar as pests than as food (Looy et al. 2014). Proponents argue that U.S. antipathy for insects is nothing more than cultural prejudice and that cultural barriers can be knocked down in time (Eha 2016). As U.S. customers do not have a culture of eating insects, a fundamental issue in increasing acceptance is to reduce the level of risk perceptions by effectively delivering correct information (Baker et al. 2016). The key to increasing customer acceptance is to maximize the benefits and minimize the risks and to understand the potential target market segments. Such risk factors, which are discussed later in the chapter include fear, disgust, physical risks, and functional risks. The mixed attitude of interest and disgust of U.S. consumers towards entomophagy adds a layer of complexity to the study of customer acceptance of insects as food (Tan et al. 2016).

3 Potential Target Market Segments in the U.S.

As it is established that U.S. consumers are one of the cultures that is most slow to adopt eating insects, it is vital to identify those segments of customers that are more likely to try edible insects, and more likely to purchase edible insect products. Currently, the three market segments of target customers are health conscious customers, environmentally conscious customers, and unique experience seeking customers.

3.1 Health Conscious Consumers

With population growth, food waste, increased greenhouse gas emissions, and decreasing land and water availability, the United Nations urges for the promotion of edible insects as an alternative food source (Baker et al. 2016; Van Huis et al. 2013). Insects can be a valuable source of high quality protein and a wide variety of vitamins and minerals (Van Huis 2013). Health conscious consumers are found to be more likely to make food choices and purchases that communicate the health benefits as a protein substitute (de Boer et al. 2013). On the other hand, the likelihood of consuming edible insects is less likely for those that have a stronger focus on the taste or satisfaction acquired from traditional meat consumption than with those that have a stronger belief that meat is nutritious and healthy (Verbeke 2015). This is likely to be the case for U.S. consumers as according to the FAO, U.S. consumers consume the most meat per person per year (Smith 2016).

Cricket powder protein bars are currently some of the more successful insect-based food products sold in the U.S. These are purchased by health conscious consumers who want to increase the protein intake in their diets as research finds that increased protein can improve physiological functions and help play a role in managing body weight (Fulgoni 2008). In addition, cricket protein bars have also found a particular market with individuals on the Paleo diet. The Paleo diet is based on the types of foods presumed to have been eaten by early humans and consists primarily on protein (beef, chicken, fish), fresh fruits and veggies, eggs, nuts, seeds, and healthful oils while eliminating grains, legumes, dairy, refined foods, and processed foods. Perhaps most interestingly, cricket flour is gaining traction as a substitute to traditional flour as it is higher in protein and does not contain gluten. These new products available in the U.S. include cricket flour, which can be used as a substitute for all-purpose flour in any recipe (Eha 2016). It is therefore an excellent option to the ever growing number of consumers who are gluten intolerant or gluten sensitive which is 1% of the population (Beyond Celiac 2016) In addition, by 2020 the gluten-free market is projected to be valued at 7.59 billion U.S. dollars (Statista 2017).

3.2 Environmentally Conscious Consumers

Sustainability benefits of edible insects include lower environmental impacts such as land use, water use, and greenhouse gas emissions. Entomophagy can contribute towards the goals of sustainable consumption because it can positively contribute to reducing the negative environmental impact of food production while also offering nutritious food to people on a global scale (Dermody and Chatterjee 2016). Crickets, for example, are 20× more efficient as a source of protein than beef, produce 80× less methane gas, and need 6× less feed (U.N. Food and Agriculture Organization). Environmentally conscious consumers are more likely to purchase products that demonstrate their pro-environmental behavior (Baker et al. 2013). Similarly, individuals who place an importance on the environmental impact of their food choice will be more likely to adopt insects as a meat substitute (Verbeke 2015). As such, an important market segment to target are those individuals who are environmentally friendly. More specifically, edible insects can be targeted to environmentally conscious consumers as they have a low environmental impact (Megido et al. 2016). In addition, environmentally friendly consumers are not only found to purchase more sustainable products, but may also be willing to pay more for these products (Baker et al. 2013).

3.3 Unique Food Experience Consumers

The third important target customer segment are those seeking unique food experiences. Eating insects can be seen as a novel, unique experience, especially as it is not a traditional part of the U.S. cultural diet. The rise in adventurous eating and eaters is a viable target market. Insect eating can be positioned as a global or adventurous experience (Taylor 2015). Interestingly, some restaurants are serving insect dishes and a number of customers are intrigued by the inventive and interesting meal offerings as it resonates with the risky and adventurous self (Dermody and Chatterjee 2016). There are an increasing number of restaurants that are serving insects as a delicacy (Verkerk et al. 2007). In both hospitality and tourism sectors, customers are increasingly looking for unique experiences and targeting these customers may be another untapped source to increase appreciation and acceptance of entomophagy.

In addition, people who have already eaten insects have a significantly more positive attitude toward entomophagy and are more willing to eat and purchase insect products (Megido et al. 2016). Initial disgust with respect to a specific food can be turned into a preference (Van Huis 2013). Only a few decades ago, U.S. consumers were disgusted by the idea of eating raw fish. However, today sushi is one of the most popular foods throughout the U.S. and is found throughout restaurants and grocery stores. Creating delicious food and targeting social appeals may be another successful strategy to gaining customer acceptance. Adventurous eaters and those looking for unique experiences may therefore be an important segment to target. These individuals are not only more likely to repeat purchase edible insect foods, but can also aid in making edible insect consumption more socially acceptable in the U.S.

4 Barriers to Insect Consumption in the U.S.

If edible insect consumption is going to increase in the U.S., the major barriers need to be understood and strategies to minimize the barriers need to be executed. In the current market, the major barriers to acceptance are cultural barriers, food neophobia, perceptions of disgust, and risk perceptions.

4.1 Cultural Barriers

At the moment, many cultural and psychological barriers stand in the way of consumer acceptance of insects as food in Western cultures (Lensvelt and Steenbekkers 2014; Looy et al. 2014). However, human-food relationships can be altered both positively and negatively and can change over time as a result of socio-economics, culinary innovation (Halloran et al. 2014), marketing, education, and public policy. Cultural exposure can act as a primary factor in influencing consumer's food choice acceptance or rejection (Dermody and Chatterjee 2016). Several years ago, eating insects in the U.S. was virtually unheard of. Today, there are an increasing number of farms that produce edible insects (Big Cricket Farms, Entomo) as well as food products being produced and sold (Chapul, Exo, Chirps) as well as insect based dishes being sold in restaurants across the United States. While cultural beliefs still remain an obstacle, there is traction that these cultural beliefs are shifting and that consuming edible insects is becoming more acceptable and increasing.

4.2 Food Neophobia

Perhaps one of the largest barriers to acceptance for edible insects throughout the world in food neophobia. Food neophobia examines the fear of trying new foods (Verbeke 2015) and is a basic human reaction to reject unfamiliar food and protect the body from possible physical hazards (Cooke 2007). An individual's level of food neophobia is a key determination of acceptance or rejection of a novel food (Verbeke 2015). In addition, food neophobia is found to have negative impacts on intentions to purchase, attitudes towards new foods, and willingness to try (Arvola et al. 1999). Food neophobia is found to be the most important factor to determine consumers' readiness to adopt insects as a food source (Verbeke 2015), which is the position of insects in the U.S. Conversely, neophilia is a general human inclination of enjoying a wide range of new and unfamiliar foods (Meiselman et al. 2010).

As such, it is critical to identify both neophobia and neophilia consumers. Consumers who are neophobic are very unlikely to try edible insects, much less regularly consume them. Individuals are open to trying new foods are a much more viable target market segment, especially in the U.S.

4.3 Perceptions of Disgust

People's aversion to insect eating remains firm in Western cultures (Van Huis et al. 2013). Disgust is a significant obstacle in fostering gastronomic acceptability to entomophagy (Baker et al. 2016). Disgust is a core emotion that triggers avoidance thoughts and behaviors. For a majority of U.S. consumers, they cannot get past the idea that eating insects is "disgusting". While the perception of disgust is clear, what is less clear is how to minimize perceptions of disgust. Very little research has examined the psychology and marketing behind edible insect consumption (Baker et al. 2016). However, U.S. consumers are more likely to experience psychological inhibitions and reactions to both the idea of eating insects as well as physically consuming them (Dermody and Chatterjee 2016). More research is needed to understand the psychological identity of consumers willing to eat insects as part of their nutritious or sustainable consumption behaviors. It is therefore important to understand the interplay between disgust and fear, and their influence on acceptability (Dermody and Chatterjee 2016).

4.4 Risk Factors

Despite the numerous benefits, most U.S. consumers perceive eating insects as a disgusting, high risk activity (Baker et al. 2016). The degree of unfamiliarity and negative feelings associated with edible insects makes consumers perceive them as high risk, resulting in major barriers in the promotion of edible insects as food products (Baker et al. 2016). When faced with uncertainty, consumers often view a new product as either a set of benefits received or risk incurred (Phillips and Hallman 2013). In order to mitigate risk, marketers and product developers need to understand how consumers form risk perceptions about new food products (Phillips and Hallman 2013) such as edible insects.

Functional risk arises when consumers anticipate possible losses from the purchased product not being able to perform its expected functions (Jacoby and Kaplan 1972). In the case of edible insects, consumers may feel that these products will not alleviate hunger, provide nutrition, or taste delicious. In terms of physical risk, consumers may not distinguish edible insects from disease transmitting insects (Baker et al. 2016). Western consumers have strong negative associations with the origins and nature of the insects (Tan et al. 2015). On a genetic level, consuming novel foods, such as insects, are rejected on an evolutionary basis as human instinctive nature causes people to avoid foods deemed as harmful or unknown, thus protecting against disease and sickness (Hamerman 2016).

5 Marketing Initiatives to Minimize Risk

Understanding customers and how they may be more likely to adopt entomophagy is the first step toward a better understanding of customer's reactions and acceptance (Baker et al. 2016).

5.1 Image Presentation

Creating appealing products plays a critical role in the acceptance of insects as food (Deroy et al. 2015; Tan et al. 2015), as a lack of acceptance has often been attributed to low sensory appeal (Baker et al. 2016; Deroy et al. 2015). It is critical to understand how and why sensory cues, such as food appearance and description, can be marketed to increase acceptance and consumption. When consumers wish to purchase or try new food, the appearance of the food is a critical factor. In the U.S., the physical appearance of insects is not compatible with U.S. customers' notion of what food should look like (Tucker 2014). Product preparation (Tan et al. 2015) and the form of the product (Baker et al. 2016) greatly affect willingness to try edible insects.

Entrepreneurs of Exo and Chapul note that insect images are not displayed on packaging (Eating Insects Detroit 2016). This corresponds with the results from marketing and psychology researchers which find that obvious images of insect on product packaging decreases customer willingness to try (Baker et al. 2016). In addition, both researchers and practitioners have found that making insects into food involves transforming the insects into another form (Baker et al. 2016; Stock et al. 2016). In the U.S., this involves creating cricket flour to be used in products as opposed to whole crickets. U.S. consumers don't want to see a picture of the animal they are eating on the products. In addition, as insects trigger additional perceptions of disgust, obvious images of insects on products is found to decrease purchasing intention. Similarly, powered forms of insects are found to be more preferable to U.S. consumers than whole insects.

5.2 Descriptions

The name of a product and how it is described can also influence purchase intentions (Kim and Baker 2017). Verbal and description cues are of critical importance in increasing U.S. consumer acceptance of insects as food. For example, changing the name of the insect food influences perceptions of expected liking and purchase intentions (Baker et al. 2016; Deroy et al. 2015). In addition, the wording associated with product descriptions can reduce negative perceptions such that more ambiguous descriptions decreased risk perceptions as opposed to obvious insect descriptions (Baker et al. 2016). For example, in the U.S., carmine is a food dye from boiled beetles that has been used for decades in products such as juices and yogurt. Shellac, made from the lac insect, is a shiny coating used for many candies and jelly beans. When labeled on foods, the names are more scientific or ambiguous and do not specifically state the food product contains edible insects. This has been found to be a more successful marketing strategy in the U.S. It should be noted, however, that customers in the U.S. are increasingly more concerned about knowing where their food comes from, and may be less satisfied with ambiguous descriptions. In addition, food labeling laws are ever changing, and it is important to be truthful in menu and food labeling. As such, how to label and describe edible insect components is a balancing act for producers and marketers.

5.3 Addressing Fear, Disgust, and Trust

It is important to understand the interplay between disgust and fear, and their influence on acceptability (Dermody and Chatterjee 2016), especially as it relates to edible insect foods. Disgust and fear are the most major impediments to human insect consumption across the world's population (Ruby et al. 2015). Disgust toward entomophagy can be decreased and acceptance increased via social and intellectual appeals (Sheppard and Frazer 2015). More specifically, consumers require tailored media communication and educational programs that address the disgust factor (Van Huis et al. 2013) especially in the U.S. (Baker et al. 2016). This currently comes in the form of television programs and media that education and entertain U.S. consumers on edible insect products.

In addition, a key antecedent to risk perceptions is trust (Phillips and Hallman 2013). Consumers believe information about risk that is provided by trusted sources, and do not believe information that is provided by untrusted sources (Kuttschreuter 2006). Higher levels of trust in the source of the information lead to higher perceptions of perceived benefits of the product. In other words, it is crucial that consumers trust the information about edible insects from the firms as well as regulators. Currently, there is a lack of research and information regarding how customers perceive trust levels of various constituents with regard to edible insect foods.

6 Marketing Initiatives to Increase Benefits

Marketing initiatives to address benefits are vital in the increased acceptance of entomophagy. Three important elements include increasing familiarity, public policy, and education.

6.1 Increase Familiarity

Food acceptance is mostly based on sensory and pleasure considerations (Van Huis 2013). Possibly the most difficult task in expanding the value of entomophagy is getting people to accept the practice (Yen 2010) through effective marketing. Familiarity with the idea of eating insects increases the intention and actual consumption (Verbeke 2015). Familiarity or unfamiliarity is an important driver of food choice and a significant determinant of the decision to replace meat by meat substitutes (Hoek et al. 2011). In the U.S., consuming insects is not embedded in the traditional diet. Furthermore, only recently have companies begun developing ways to market or present insects to the U.S. consumer (Fellows 2014). The unfamiliarity of insects as food in the U.S. poses many difficulties to product development as prior taste experiences form the basis for expectations and knowledge. As the U.S. is not an insect eating culture, their expectations are less distinct (Tan et al. 2016). One successful strategy is for experimental tasting events that allow consumers to see, feel, and taste insects in new ways in order to familiarize them with insects as food and increase acceptance (Stock et al. 2016).

6.2 Education

Education is a key strategy. While some research finds that consumers are not willing to change their consumption behaviors to become more sustainable (Rettie et al. 2012), other research finds that education and increasing knowledge is key to behavioral change. To increase customer acceptance of edible insect foods, it is important to educate consumers on the cultural, nutritional, and environmental issues of entomophagy (Megido et al. 2016). Research and education regarding the value of insects as a food source can reduce negative perceptions and increase purchase intentions (Yen 2009).

In the U.S., human consumption of insects is infrequent or even culturally taboo, which results in it rarely being discussed as part of the sustainability and food security agendas of international organizations (Van Huis 2013). Media, emergent entomophagy networks and businesses providing information on the benefits of insects as food will aid in increased acceptance (Stock et al. 2016). U.S. organizations such as Eat Yummy Bugs and Little Herds are educating people about the environmental and health benefits of eating insects. In addition, entrepreneurs, food scientists, farmers, researchers, and academics are convening at conferences to discuss cutting edge research and product development for edible insects (Eating Insects Detroit, 2016).

6.3 Public Policy

Currently, there are few regulatory frameworks that exist in the U.S. regarding production, trade, and consumption regulations in the U.S. (Grabowski et al. 2013). Growing amounts of lobbying from insect farmers, producers, and consumers have put insect consumption on the radar of decision-makers (Halloran et al. 2014). Legislation needs to include insects as food and feed to improve existing national policy and legal frameworks (Halloran et al. 2014). In addition, more research is needed to understand the role public policy plays in increasing perceptions of benefits and deceasing risk perceptions.

It is important to note that there is significant work that needs to be done with regard to public policy and legislation of edible insects in the United States. Risk assessment including allergy testing needs to be conducted with insects. Specifically, as many insects used in food products such as crickets and mealworms have an exoskeleton, individuals who are allergic to shellfish may have similar allergic reactions to these insects. As such, there is a need for more research and legislation as to how food products should be designed, labeled, and marketed (Van Huis 2013). It is important to influence the public as well as policy makers and investors in the food sector by providing validated information on the potential of insects as food and push insects higher on political, investment, and research agenda (Van Huis et al. 2013).

References

Arvola A, Lahteenmaki L, Tuorila H (1999) Predicting the intent to purchase unfamiliar and familiar cheeses: the effects of attitudes, expected liking and food neophobia. Appetite 32:113–126

Baker MA, Davis EA, Weaver PA (2013) Eco-friendly attitudes, barriers to participation, and differences in behavior at green hotels. Cornell Hosp Q 55(1):89–99

Baker MA, Shin JT, Kim YW (2016) An exploration and investigation of edible insect consumption: the impacts of image and description on risk perceptions and purchase intent. Psychol Mark 33(2):94–112

Beyond Celiac (2016) Celiac disease: fast facts. Retrieved from https://www.beyondceliac.org/celiac-disease/facts-and-figures/

Cooke L (2007) The importance of exposure for healthy eating in childhood: a review. J Hum Nutr Diet 20:294–301

de Boer Joop, Schösler H, Boersema JJ (2013) Climate change and meat eating: An inconvenient couple?. Journal of Environmental Psychology 33:1–8

Dermody J, Chatterjee I (2016) Food glorious food, fried bugs and mustard! Exploring the radical idea of entomophagy in advancing sustainable consumption to protect the planet. In: Competitive paper in conference proceedings, Academy of Marketing Annual Conference, Newcastle, July, 2016

Deroy O, Reade B, Spence C (2015) The insectivore's dilemma and how to take the west out of it. Food Qual Prefer 44:44–55

Diluna A (2015) Crispy, crunchy…crickets? UConn food truck has unusual menu. Retrieved from http://www.nbcnews.com/feature/freshman-year/crispy-crunchy-crickets-uconn-food-truck-has-unusual-menu-n439216

Eating Insects Detroit Conference (2016) Exploring the culture of insects as food and feed. Wayne State University, Detroit

Eha BP (2016) This whole eating bugs thing actually has legs. Retrieved from http://fortune.com/2016/04/18/eating-bugs-insect-protein/

Fellows P (2014) Editorial: insects for food and feed. Food Chain 4:101–102

Fulgoni VL (2008) Current protein intake in America: analysis of the National Health and Nutrition Examination Survey, 2003–2004. Am J Clin Nutr 87(5):1554S–1557S

Grabowski N, Kein G, Lopez AM (2013) European and German food legislation facing uncommon foodstuffs. Crit Rev Food Sci Nutr 53(8):787–800

Halloran A, Muenke C, Vantomme P, van Huis A (2014) Insects in the human food chain: global status and opportunities. Food Chain 4(2):103–118

Hamerman EJ (2016) Cooking and disgust sensitivity influence preference for attending insect-based food events. Appetite 96:319–326

Hay M (2016) Here's why you should be eating bugs. Tasting table. Retrieved from https://www.tastingtable.com/cook/national/bug-eating-crickets-mealworms-exo

Hoek AC, Luning PA, Weijzen P, Engels W, Kok FJ, de Graaf C (2011) Replacement of meat by meat substitutes. A survey on person- and product related factors in consumer acceptance. Appetite 56:662–673

Jacoby J, Kaplan LB (1972) The components of perceived risk. Adv Consum Res 3:382–383

Kim KK, Baker MA (2017) The impact of service provider name, ethnicity, and menu information on perceived authenticity and behaviors. Cornell Hosp Q 58:312–318

Kuttschreuter M (2006) Psychological determinants of reactions to food risk messages. Risk Anal 26:1045–1057

Lensvelt EJ, Steenbekkers LPA (2014) Exploring consumer acceptance of entomophagy: a survey and experiment in Australia and the Netherlands. Ecol Food Nutr 53(5):543–561

Looy H, Dunkel FV, Wood JR (2014) How then shall we eat? Insect-eating attitudes and sustainable foodways. Agric Hum Values 3(1):131–141

Megido RC, Gierts C, Blecker C, Brostaux Y, Haubruge É, Alabi T, Francis F (2016) Consumer acceptance of insect-based alternative meat products in Western countries. Food Qual Prefer 52:237–243

Meiselman HL, King SC, Gillette M (2010) The demographics of neophobia in a large commercial US sample. Food Qual Prefer 21:893–897

Menozzi D, Sogari G, Veneziani M, Simoni E, Mora C (2017) Eating novel foods: an application of the Theory of Planned Behaviour to predict the consumption of an insect-based product. Food Qual Prefer 59:27–34

Phillips DM, Hallman WK (2013) Consumer risk perceptions and marketing strategy: the case of genetically modified food. Psychol Mark 30(9):739–748

Rettie R, Burchell K, Riley D (2012) Normalizing green behaviors: a new approach to sustainability marketing. J Mark Manag 28(3–4):420–444

Ruby MB, Rozin P, Chan C (2015) Determinants of willingness to eat insects in the USA and India. J Insects Food Feed 1(3):215–225

Sheppard B, Frazer P (2015) Comparing Social and Intellectual Appeals to Reduce Disgust of Eating Crickets. Studies in Arts and Humanities 1 (2):4–23

Smith O (2016) Mapped: the countries that eat the least (and most) meat. The telegraph. Retrieved from http://www.telegraph.co.uk/travel/maps-and-graphics/world-according-to-meat-consumption/

Statista (2017) U.S. Gluten-free foods markets. Retrieved from https://www.statista.com/topics/2067/gluten-free-foods-market/

Stock PV, Phillips C, Campbell H, Murcott A (2016) Eating the unthinkable. In: Le Heron R, Campbell H, Lewis N, Carolan M (eds) Biological economies: experimentation and the politics of agri-food frontiers. Routledge, London/New York, pp 157–169

Tan HSG, Fischer AR, Tinchan P, Stieger M, Steenbekkers LPA, van Trijp HC (2015) Insects as food: exploring cultural exposure and individual experience as determinants of acceptance. Food Qual Prefer 42:78–89

Tan HSG, van den Berg E, Stieger M (2016) The influence of product preparation, familiarity and individual traits on the consumer acceptance of insects as food. Food Qual Prefer 52:222–231
Taylor K (2015) How food makers are convincing America to eat bugs. Retrieved from https://www.entrepreneur.com/article/238232
Tucker CA (2014) The significance of sensory appeal for reduced meat consumption. Appetite 81:168–179
Van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583
Van Huis A, Van Itterbeeck J, Klunder H, Mertens E, Halloran A, Muir G, Vantomme P (2013) Edible insects: future prospects for food and feed security (No. 171). FAO of the United Nations.
Verbeke W (2015) Profiling consumers who are ready to adopt insects as a meat substitute in a Western society. Food Qual Prefer 39:147–155
Verkerk MC, Tramper J, Van Trijp JCM, Martens DE (2007) Insect cells for human food. Biotechnology Advances 25:198–202
Yen AL (2009) Edible insects: traditional knowledge or western phobia? Entomol Res 39:289–298
Yen AL (2010) Edible insects and other invertebrates in Australia: future prospects. In: Durst PB, Johnson DV, Leslie RL, Shono K (eds) Forest insects as food: humans bite back. FAO Regional Office for Asia and the Pacific, Bangkok, pp 65–84

Means-End Chain Approach Explains Motivations to Consume Insect-Based Foods: The Case of Cricket-Scones in Kenya

Kennedy O. Pambo, Julius J. Okello, Robert M. Mbeche, and John N. Kinyuru

Abstract Edible insects are being promoted as a sustainable and inexpensive alternative of enhancing nutrition because they can provide proteins, good fats such as the polyunsaturated fatty acids (PUFAs), calcium, vitamins, and energy. But little is known regarding what drives individuals to consume insect-based foods. The current study seeks to explain the effect of personal values on "cricket-scones" (used interchangeably with cricket-based scones) consumption in a developing country's context. Employing laddering interviews and the means-end chain analysis, the relationship between "attributes" of cricket-scones, "consequences" of consuming them (outcomes), and personal "values" driving consumers' decision-making process were systematically mapped to generate mental models related to consuming insect-based products. The personal values identified in this study cluster under the headings of "happy life", "(food) security", and "long life". Amongst these, the main evidence (ladders) pointed to the desire to have a "happy life" and a "long life" that arise from improved family nutrition and financial position. Moderating these results by gender revealed higher involvement for males. The findings suggest that cricket-scones enhance the goals of achieving core personal values. Campaigns aiming to promote edible insects should therefore be premised on local food policies designed along the identified consumer-motivations. Other than the common nutritional and environment-friendly themes that have been used to promote edible insects; "happy life", "(food) security", and "healthy life" themes emerged as the central messages for the development of insect-based foods' campaign strategies. Other empirical information in this study also have insightful policy implications.

K. O. Pambo (✉) · R. M. Mbeche · J. N. Kinyuru
Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

J. J. Okello
International Potato Center, Kampala, Uganda

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_25

1 Introduction

Interests in insect-based foods have recently gained momentum in Kenya with the local media indicating a particular attention. For instance, the Standard Media Group through the Kenya Television Network and the Standard Newspaper published "*Experts*: *Eating locusts and crickets is good for you*" (May 18, 2015); "*Eat insects for better health*" (January 20, 2016); "*Research aimed at fostering food security in Kenya through insects is underway*" (September 12, 2016), "*Farmers in Kenya develop taste for insects as drought hurts crops*" (February 18, 2017). The Nation Media Group through the Nation Television and the "*seeds of gold magazine*"[1] – a pull-out in the Saturday Nation Newspaper, carried articles titled "*New on plate: Biscuits made from crickets*" (August 2, 2014); "*Eat insects to improve nutrition, say scientists*" (March 5, 2016); and "*Time to enjoy insect delicacy as cricket farming takes root in Kenya*" (July 16, 2016). The Royal Media Group through CITIZEN Television, published "*Scientists want Kenyans to consume more crickets for improved nutrition*" (August 30, 2016). Indeed, the consumption of edible insects has been a traditional practice of many communities, especially to the western region of Kenya (Christensen et al. 2006; Pambo et al. 2017). However, the artificial rearing and processing of some insects, especially crickets, has taken a completely different business approach i.e. commercial rather than the subsidence manner of the traditional system.

Recent studies (for example, Pambo et al. 2016; Pambo et al. 2017; Alemu et al. 2017) suggest high demand for insect-based foods and that the supply side is investing in modern methods of production with support from the scientific community. Efforts are being directed at increasing the supply (hence access) of insect-based foods. For instance, the "Flying Food" project alone, trained more than 1000 farmers from 2011 to 2013. Additionally, the "GREEiNSECT" and "INSFEED" projects have also approximately trained the same number of farmers (since 2014) on technologies that aim to make insect-based foods available throughout the year, at a reasonable price and in different forms (ICCO 2013; Pambo et al. 2016). The pertinent question remains regarding what drives the consumption of insect-based foods.

The current chapter, therefore, investigates what motivates consumption of insect-based foods by analyzing consumers' mental models regarding cricket-scones. Additionally, the study explores whether differences in mental models are gender-specific, i.e. whether the structure of decision-making relating to consumption of insect-based foods is different between male and female consumers. The study differs from other studies that have investigated acceptance/preferences for foods from edible insects (for example, van Huis 2013; Lensvelt and Steenbekkers 2014; Alemu et al. 2017; Pambo et al. 2018) by exploring the meaning representations associated with the decision to consume insect-based foods.

[1] *Seeds of Gold*: Egerton University in partnership with the Nation Media Group (NMG) launched an Agribusiness magazine that targets to enhance farmers' knowledge on the best farming practices and transfer newly developed innovations and technologies to farmers.

The rest of this chapter is organized as follows: In the next two sections, i.e. Sects. 2 and 3, we describe the theoretical framework and research methods. Section 4 presents the results; first, for the whole sample, and then for male and female participants of the study, separately. Lastly, Sect. 5 presents the conclusions and summarizes the policy implications of the major findings.

2 Theoretical Framework

The means-end chain (MEC) theory was applied to explain consumers' mental models, which inform their decision-making process. In this context, MEC posits that an individual would consume foods from edible insects (cricket-based scones in the current case) (means) to generate particular benefits (consequences) that will ultimately serve to attain more abstract personal values (end) that s/he associates with the consequence (Barrena and Sánchez 2009). Thus, the MEC approach is suitable for understanding consumers' motivations in their decisions regarding the consumption of foods from edible insects. The theory (Fig. 1) posits that perceived self-relevant product attributes lead to consequences, which again lead to certain personal values being fulfilled.

Attributes are normally associated with one or several consequences, the desired outcomes (benefits) that an individual want from a product (Okello et al. 2013; Arsil et al. 2014). These consequences can be direct, indirect, physiological, psychological or sociological in nature (Lind 2007). For example, "locally available" (an attribute) of crickets can be associated with proper utilization of local resources (first consequence), which then either creates employment opportunities or helps in maintaining local diversity (second consequence). Values are the end states of MEC and are cognitive representations of an individual's existential goals (Lagerkvist et al. 2012). They are similar to needs/desires that motivate the actions taken or decisions made by an individual. Values represent standards that guide thought and action i.e. translates individual needs into a socially acceptable format (Lind 2007;

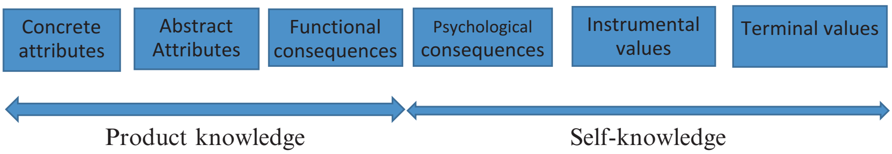


Fig. 1 Six-dimensional means-end chain (Concrete attributes are tangible/physical characteristics of the product, whereas abstract attributes are intangible/subjective characteristics of the product. Functional consequences are of a more physiological nature, as they typically satisfy basic needs like thirst or hunger or some more practical consequences of a product's attributes, such as saving time or holding a budget. Psychological consequences are more personal consequences of the use/purchase of a product. The relation between the instrumental and the terminal values consists of the notion that instrumental values are modes of behavior that are socially desirable and perceived as effective, to achieve the desired end-states that make up terminal values (Olson and Reynolds 2001)

Arsil et al. 2014). Therefore, by investigating the MEC related to consumption of cricket-scones, the inner motives of consumers' choices regarding insect-based products are determined. Understanding such motives is imperative for the development of marketing strategies aimed at increasing consumption foods from edible insects to improve both the nutrition and the incomes of individuals in the targeted rural households.

Following Okello et al. (2013), an attribute-consequence-value (A-C-V) sequence forms a chain referred to as a ladder. A collection of all the ladders for a given domain forms a hierarchical value map (HVM) that illustrates all the major means and end values, and describes individuals' behavior based on their personal values. The maps usually contain many product attributes that are linked to a set of consequences, which in turn, are mapped to a core set of personal/core values. The HVM maps basically represent how various constructs related to a product (i.e., A-C-V) are mapped (i.e. arranged) in an individual's mind, and are sometimes referred to as mental representations of the laddering constructs (mental models).

The laddering technique is normally used to assess personal values because of its ability to "bring to the surface" the values that are usually hidden within individual's mind (Reynolds and Gutman 1988). The technique has its roots in personal construct theory developed by Kelly (1955) and has been used extensively in many consumer studies that attempt to delve into the sub-conscious world of an individual's mind (Lind 2007; Barrena and Sánchez 2009). It has recently been applied by Lagerkvist et al. (2012) and Okello et al. (2013) in safety perception and soil fertility management of fresh vegetables by farmers, and by Arsil et al. (2014) to explore consumer' motivations towards local foods.

Following Lind (2007, p. 692) HVMs can be used to infer consumer involvement.[2] When the consumer is highly involved or has deeper knowledge about the product, a larger number of chains are elicited by the respondent (Arsil et al. 2014). Low involvement products have simpler and less interconnected maps than high involvement products. Based on the number and the complexity of the derived paths, this study explores whether cricket-based scones is more involving in either male or female consumers. Low involvement products are not important to the individual's self-concept (Pieters et al. 1995). Involvement is dependent on the self-relevance of product-values and on the strength of the connections between the product knowledge (attributes and functional consequences) and the self-knowledge (psychosocial consequences and values). It is expected that female consumers will be more involved than their male counterparts because they exhibit a more "virtuous" food choice pattern (Beardsworth et al. 2002). Food consumption is usually repeated and routinized activity that normally draws less expertise from consumers. As such, most food products yield abstract attributes and consequences, meaning that consumption-decisions are generally characterized by relatively low levels of involvement (Lind 2007).

[2] "Personal involvement" refers to how a person is attached to a product i.e. consumers who are highly attached to a product will actively search for and use information about the product to make informed choices (Zaichkowsky 1985).

3 Empirical Methods

3.1 Study Area and Sampling

Primary data was collected from Siaya and Machakos counties in Western and Eastern regions of Kenya, respectively (Fig. 2). Consumption of edible insects is common in Siaya, but uncommon in Machakos county. These counties have also hosted several interventions that aim to promote the use of (Münke-Svendsen et al. 2016) which made them suitable for this study.

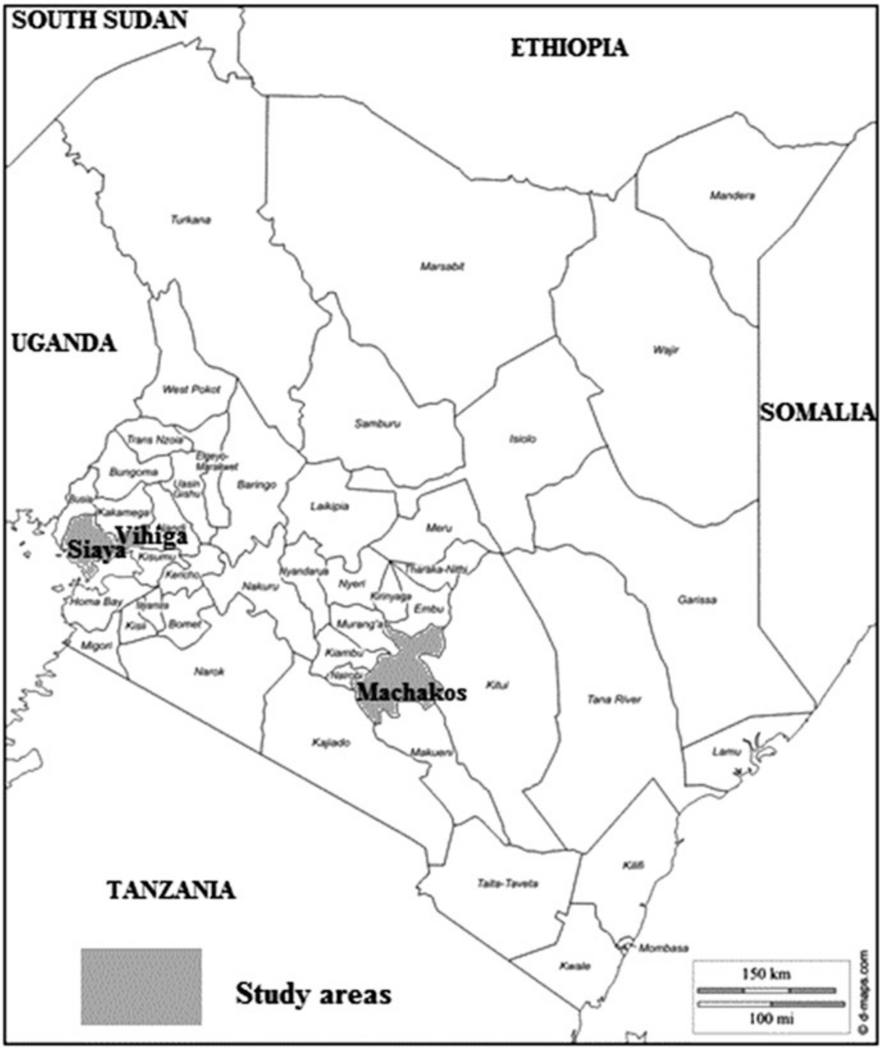


Fig. 2 Geographical regions where the study was done in Kenya (d-maps.com)

The study respondents were selected as follows: from each county, four locations were randomly sampled then one sub-location selected the same way from each location. In each sub-location, a list of all the villages was drawn and three villages randomly sampled. In each sampled village, a list of all households was generated with the help of village elders out of which either two or three households (proportionate to the size of the village) were randomly sampled for the laddering interview. Either the head of the household or the spouse was interviewed. If neither of the two was available, another adult in the household who also participates in decisions regarding food purchases and preparation was interviewed. This process led to a random sample of 54 respondents whose characteristics are presented in Table 1.

Table 1 Socio-economic characteristics

Variable	Whole sample		Males		Females		Mann-Whitney[a]
	Mean	SD	Mean	SD	Mean	SD	
Descriptive							
Mean household size	4.56	1.77	4.62	1.67	4.44	1.71	0.153
Mean participants' age	45.11	12.84	46.31	12.44	44.94	11.89	0.069
Mean household income ('000)[b]	265	286	267	283	263	289	0.221
Frequencies							
	Proportion (%)		Proportion (%)		Proportion (%)		
Have consumed insect-based foods	12.5		8.33		16.67		0.058
Have consumed insects of any kind	89.58		87.5		91.67		0.066
Level of highest education							
Non-school & incomplete primary	18.75		16.67		20.83		0.049
Complete primary	39.58		33.33		45.83		0.048
Complete secondary	25		25		25		0.653
College (no university)	10.41		12.5		8.33		0.047
University	6.25		12.5		0		0.049
Marital status							
Married	85.41		87.49		83.33		0.061
Single	2.1		4.17		0		0.044
Widowed	8.31		4.17		12.5		0.051
Co-habiting	4.18		4.17		4.17		0.987
n	54		34		20		

[a]Hypothesis: the distribution of the variables for male and female participants is the same
[b]Sum of crop, livestock and other income during 2015 (in thousand Kenyan Shilling)

The sample size, though small, compares favourably with those used by other MEC studies. For example, Okello et al. (2013) used a sample of 54 kale farmers and laddering technique to investigate the role that farmers' personal values play in the decision to use two of the most widely applied soil fertility improvement inputs namely organic manures and chemical fertilizers in Kenya; Schaefers (2013) used sample sizes of eight male and six female participants to assess motivations for women and men to use car-sharing services in the United States of America; while Crudge and Johnson (2007) used repertory grid and laddering technique with only six participants to explore a method for the determination of users' "mental models" and representations of search engines, formed during their interaction with these systems.

3.2 Laddering Interviews

The laddering interviews were used to investigate what motivates consumption of insect-based foods and to explore whether differences in mental models regarding consumption of such foods are gender-specific. The laddering interviews were preceded by a field experiments[3] where participants were approached and interviewed at their homes. The home environment was considered appropriate situational context because it is where food preparation and eating mostly takes place (Lind 2007). Field experiments followed the procedure below:

Upon recruitment, the participant was asked for his/her informed consent to participate in the study. Following Alemu et al. (2017), a consenting respondent was then given the basic information on processing the cricket-scones, including the safety and quality control measures during preparation and distribution of the scones, the authorization of the study by the relevant government agencies, hence its suitability for use in the study.

Participants were then given a packet containing three cricket-scones and instructed to take one and taste. The interviewer ensured that the respondent actually tasted the scones before proceeding.[4] Participants were allowed to keep the remaining two scones for other family members to also taste after the experiment, as compensation for the time devoted to the experiment.

The cricket-based scones (a mixture of 10% cricket-powder and 90% normal wheat flour) were baked by trained technicians at the Food Processing Workshop Unit at Jomo Kenyatta University of Agriculture and Technology in Kenya based on

[3] Ethical guidelines laid down in the Declaration of Helsinki were adhered to while conducting the field experiments, and all procedures involving human subjects were approved by the Kenyatta National Hospital/University of Nairobi – Ethical Review Committee (reference KNH-ERC/A/493; Protocol reference P609/09/2015).

[4] Participants were informed that the experiment would involve tasting cricket-scones (a real insect-based food). Only those who volunteered to taste were recruited, while those who declined were requested to exit. At the end of the survey only one person exited the experiment.

a recipe adopted by Alemu et al. (2017). In addition, samples of these scones were tested to ensure suitability for the study by the Kenya Bureau of Standards before employed in the experiment.

Following Reynolds and Gutman (1988), the interviewer started each laddering session by asking the respondent to consider: (1) the cricket-based scone just tasted and, (2) the remaining two cricket-based scones.

The respondent was then asked why he/she would be interested (or not interested) in consuming the cricket-based scones (which he/she had tasted) again.

Based on the response to this question, attributes (features) that would make the respondent want to consume cricket-scones again or otherwise, were listed, and formed the starting point for the laddering interviews.

The interviewer then used a series of "*why is that important to you*" questions, which forms the premise of laddering technique,[5] to trace the A-C-V structures associated with each attribute. Evidence shows that this process of interviewing "induces" the respondents to dig into the subconscious mind and retrieve the hidden motivations, which Okello et al. (2013) referred to as mental constructs or models. These models are considered to motivate actual decisions and the associations among the constructs in the mind of the respondent. Each interview lasted for 25–40 min.

3.3 Content Analysis

Data from the laddering interviews were analyzed following the recommendations by Reynolds and Gutman (1988). The answers from the laddering interviews were classified according to whether they were attributes, consequences or values. A set of summary codes were first developed by the research team to ensure that all the attributes, consequences and values mentioned by the respondent were covered. The team was jointly trained in the use of laddering technique and MEC analysis to improve consistency during content analysis procedure as suggested by Arsil et al. (2014). MECanalyst 1.0.15 software was then used to analyze the coded data. This software produces a mental map with a summary implication matrix that indicates how often concepts that have been mentioned are linked to each other, both directly and indirectly. Following Barrena and Sánchez (2009), the number of times each variable was mentioned as the end versus the origin of a relationship was compared

[5] The initial question aimed to elicit the main product *attributes* from the participants. Based on their initial responses relating to attributes, the next questions addressed the *consequences* of the identified attributes. These are higher level of questions which forces participants to think about the *reasons* for their attribute preferences. The higher level questioning are achieved by asking questions such as the following: "*Why is this important to you? What does it mean to you? What is the meaning of this product having this attribute*"? To uncover *personal values*, employ the same type of "*Why?*" questions (refer to Reynolds and Gutman 1988, for details regarding the laddering interviews).

while ordering the matrix. The software also allows for the aggregation of the means-end chains (MEC) into a hierarchical value map (HVM). The HVM in this case depicts the motivational decision structure of the consumers' decision to consume cricket-scones (Grunert and Grunert 1995; Okello et al. 2013).

The next step in generating HVMs was to identity a "cut-off level". As Reynolds and Gutman (1988) suggested, the "rule of thumb" for researchers is to try multiple cut-off levels and then choose the HVM that produces interpretable and informative solutions. The key decision to generate the HVM is to determine which linkages in the summary implication matrix to be portrayed as the dominant relationships (Arsil et al. 2014). Additionally, the proportion of active links at or above the cut-off level can also be used as a decision criterion, with levels >50% taken as the threshold (Pieters et al. 1995).

The HVMs for the current study were constructed using cut-off levels of 4 and 3. These levels represented between 60% and 70% of active links at or above the cut-off level and was considered appropriate for choosing the cut-off level (Arsil et al. 2014). The HVMs were then graphically presented, with the attributes at the bottom of the maps and the values at the top as shown in Figs. 3, 4, and 5. The concepts were proportionally rendered with the most important concept having the boldest arrow, following Lind (2007).

4 Results and Discussions

4.1 What Motivates the Consumption of Cricket-Based Scones

The HVM for the whole sample is presented in Fig. 3. The findings showed that the respondents would be motivated to consume cricket-based scones by seven abstract characteristics, namely: good taste, attractive colour, nutritious, low levels of sweetness (less sugary) and good for the environment. The most important attributes, as determined by the majority of the respondents (Fig. 3), are good taste (63%) and nutritious (56%). It was interesting that 39% perceived the "dark" colour of cricket-based scones as "attractive" in relation to "brown" colour of conventional scones. However, 17% felt that the colour was not motivating. A third of the respondents associated the cricket-based scones with "less-sweetness" (less sugary). Surprisingly, they associated this with fitness benefits (energizing i.e. more energy or being strong). But still, 14% of the respondents perceived cricket-based scones negatively as "disgusting".

The general HVM shows that the sensory attributes are mainly mentally associated with functional consequences, namely: more-appetite, enabling them to either "enjoy eating", "eat more" or "get more energy". These are further mentally linked to separate chains that include becoming stronger and ability to work. These two consequences are associated, in the minds of the respondents, with two other consequences namely, earning more income (becoming wealthy) and having enough food

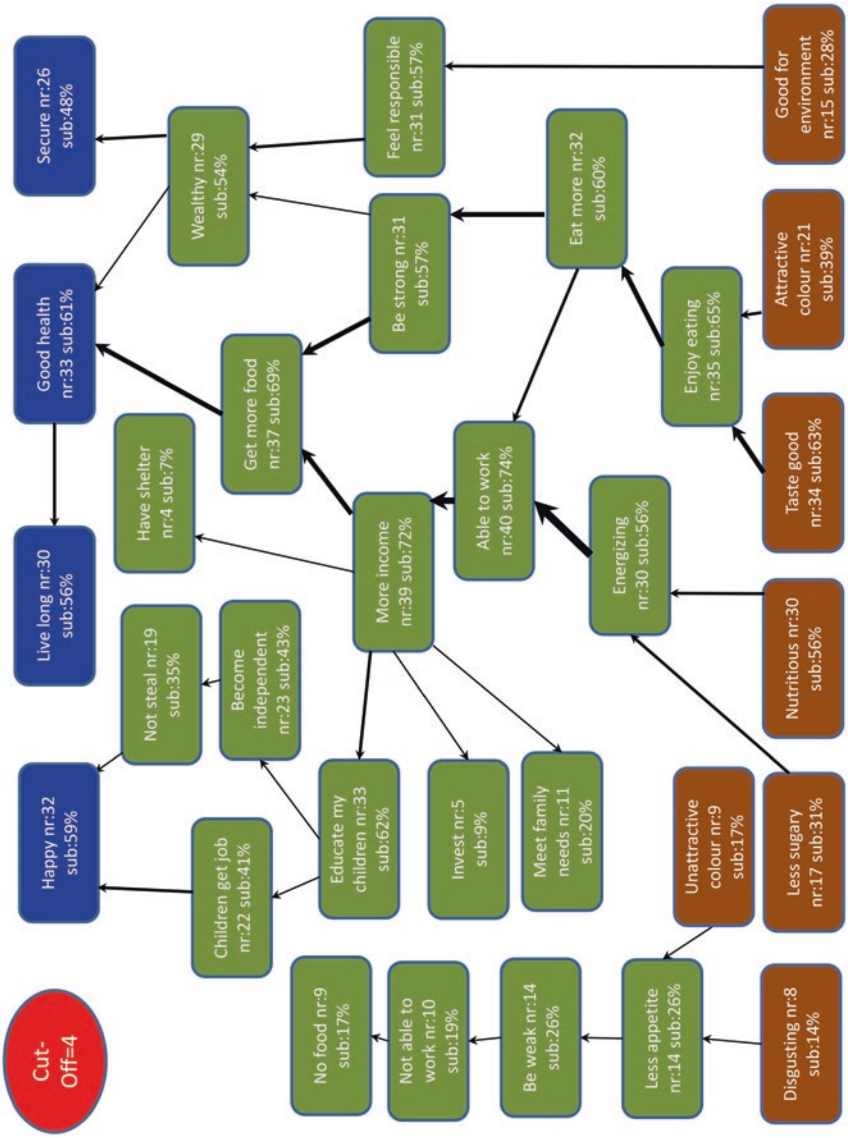


Fig. 3 The HVM for the whole sample

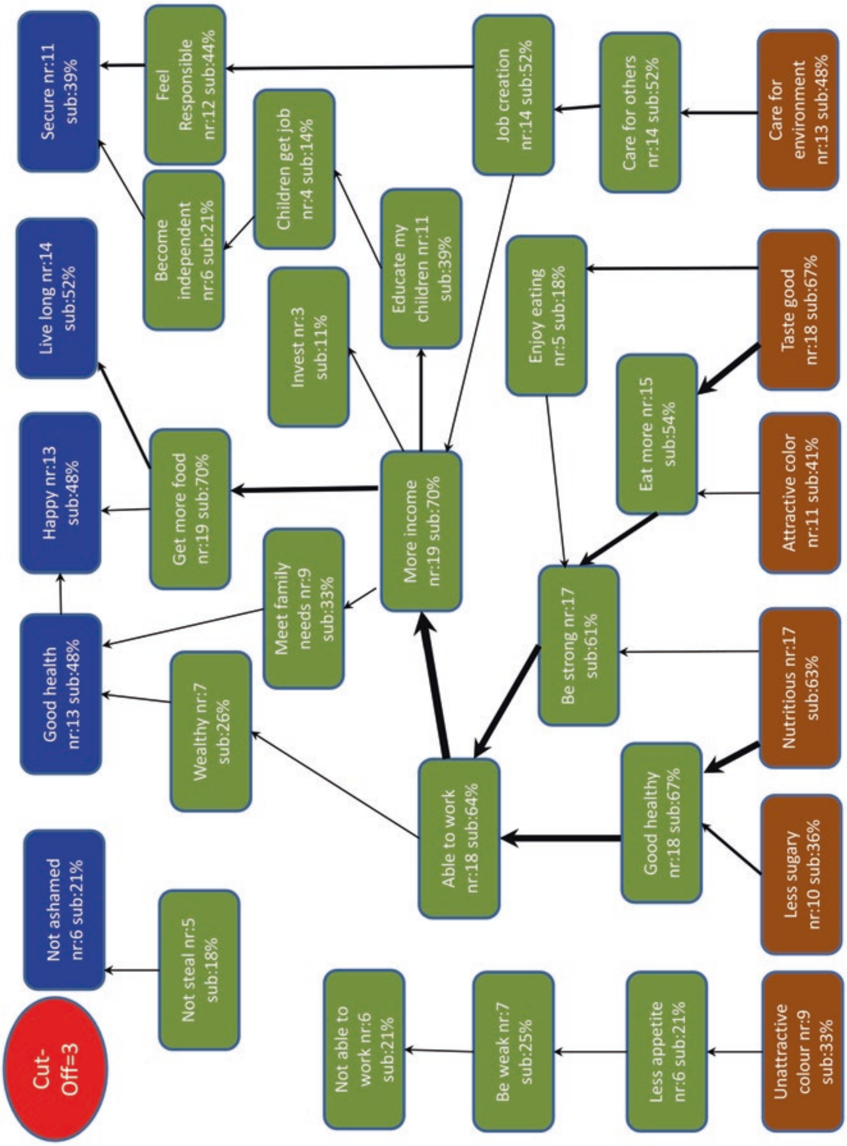


Fig. 4 The HVM for male participants

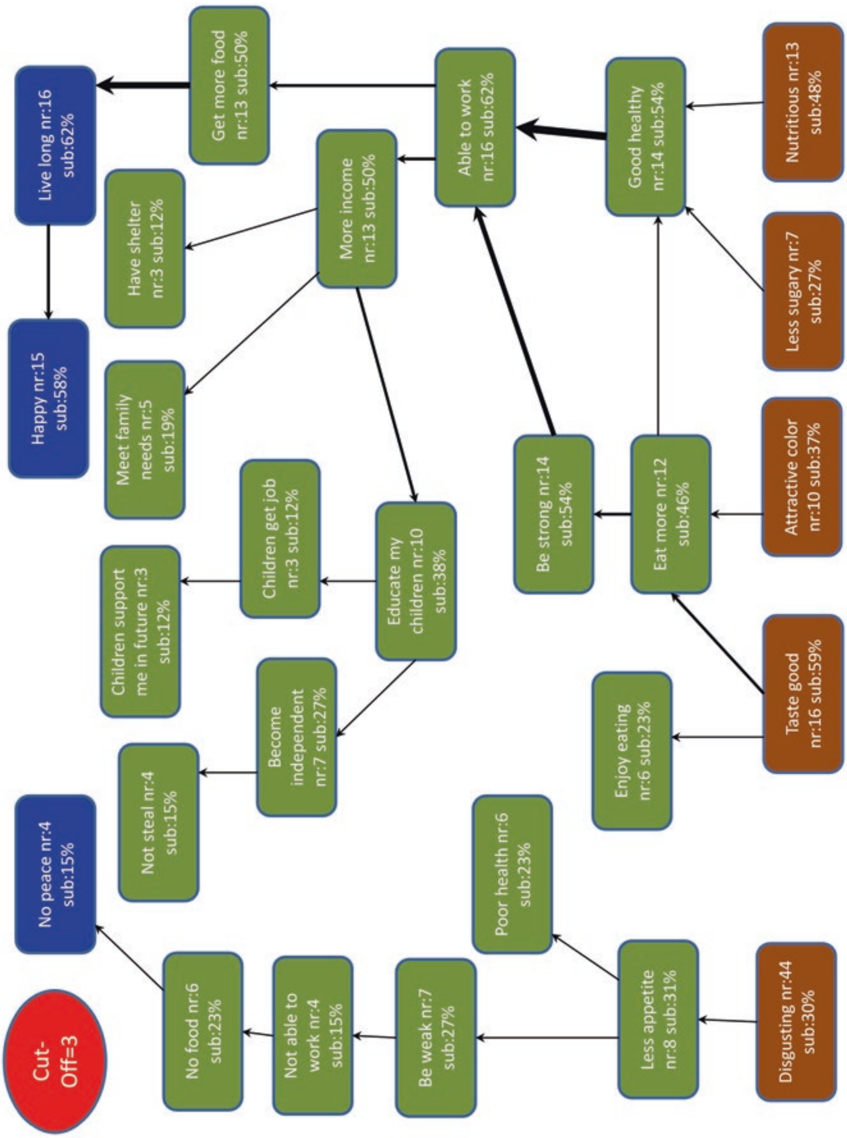


Fig. 5 The HVM for female participants

(in the family). More income is associated with several consequences, some of which are terminal, i.e. do not end up with a value. These are being able to educate children, get more food, invest in other income generating enterprises such as cricket farming, as well as the ability to meet other family needs (e.g., providing shelter, buying clothes, medical, and social/religious obligations) (all functional consequences). As shown, education of children is associated with psychological consequence of children getting good jobs (becoming independent) and hence, in turn, later supporting their parents.

Some participants mentally associated cricket-based scones with "good for the environment". They associated the attribute "good for the environment" with the psychological consequence of being responsible in the society, and further with becoming wealthy. Some participants however, perceived cricket-based scones negatively by characterizing them as "disgusting" and the dark-colour of cricket-based scones as "unattractive". These two attributes are associated with reduced appetite, which lead to low food consumption, which leads to yet another negative consequence, namely that the body becomes weak and unable to work. The negative ladder, however, ends with "lack of food" as a terminal-functional consequence.

There are four values associated with the HVM for the whole sample. These are: good health, happiness, long life and being secure. Most participants (61%) associated having more food and being wealthy with good health, which is an instrumental value that facilitates achievement of the desired end-state of long-life. This value also has the boldest connecting arrow (in Fig. 3), hence the most important construct. The terminal-value happiness is associated with own-children's good behavior and success as they either get good jobs or become self-reliant i.e. by having grown-up children who are well-behaved, independent, and who would support parents during old age. The terminal-value "(food) secure" is ultimately associated with feeling wealthy in the society.

Thus, the main reasons why the study participants would consume cricket-based scones are good taste, being perceived as nutritious and good for the environment. They would do so to be strong (energized to work) which allows them to have more food, be wealthy and earn more income to educate children, invest, and also meet other family needs. These benefits of consuming cricket-based scones, in turn enables the participants achieve three life goals (values) namely, long life, happiness and being food secure. Thus, individuals would be motivated in their decision to consume foods from edible insects by the desire to be food secure and to have a long and happy lives.

4.2 Mental Models for the Male Participants' Regarding Cricket-Based Scones

The HVM for the male participants (Fig. 4) had all the attributes contained in the HVM for the whole sample, except "disgusting". They were motivated to consume cricket-based scones, mostly by good taste (67%), nutritious (63%) and good for the environment (48%). Just like the whole-sample, the male participants associated the sensory attributes (good taste, attractive colour and less sugary) with increased appetite to eat more, get stronger and do more work (functional-consequences), and the non-sensory attribute “good for the environment” with psychological consequence.

There are some remarkable differences in the consequences of consuming cricket-based scones in the HVM for the male-participants. The attribute “good for the environment”, which was linked to feeling responsible in the HVM for the whole sample is now associated with care for others. Two unique consequences emerged namely, “job creation” and “care for others”. However, just as in the HVM for the whole sample, one incomplete negative ladder emerged from the only negative attribute in this HVM, “unattractive color”.

This HVM has all the values contained in the HVM for the whole-sample, but with an additional terminal-value “not ashamed”. This value was expected to rise from the path linking “more-income to educate children” with “having a good-family life”. Instead, another ladder started in the middle (probably due to the cut-off level) with the psychological-consequence “steal”. The male participants associated the value “food secure” with children having good jobs and becoming self-reliant. Indeed, they are driven to create jobs by carefully exploiting local resources for the benefit of others in the society. Therefore, they are motivated to consume cricket-based scones so as to be food secure and also to have healthy and long lives.

4.3 Mental Models for the Female Participants’ Regarding Cricket-Based Scones

Figure 5 present the HVM for female participants. This HVM has some marked differences from the HVM for male-participants. For instance, it has five abstract-attributes that are sensory in nature. The negative ladder is complete, and has only two terminal-values. Most consequence-associations in this HVM are terminal (not ending with a value) compared to HVM for male-participants. The chosen cut-off level (3) could have eliminated responses that were below this threshold, just as is the case in the HVM for the male participants. However, there are many incomplete chains in the HVM. It is possible that the female participants are less involved with cricket-based scones than their male counterparts, hence the many incomplete ladders.

The only positive terminal value for the female participants “happiness” results from “long life”; an instrumental value associated with having more food to eat. The female participants’ register the only negative value of the study “no peace”, due to lack of food to eat as a result of inability to work. Seemingly, they perceive negative sensory attributes of cricket-based scones (e.g. disgust) to reduce appetite, which they associate with “not eating enough” hence, inability to work, leading to both poor health (a terminal psychological consequence) and lacking food.

4.4 Involvement in Cricket-Based Scones

The number of complete ladders given by the participants and the complexity of the HVMs (Figs. 3, 4, and 5) are analyzed to infer familiarity and involvement. All the participants elicited at least two ladders and over 60% elicited more than two ladders, indicating high-involvement with the product. The conclusion is that cricket-scones are important to the participant's self-concept, hence self-relevant to consumers. The male participants (Fig. 4) however, elicited more ladders than their female counterparts (Fig. 5). Moreover, most ladders elicited by the male participants (71%) are complete i.e. they include an attribute, a consequence and a value, compared to only 25% in the HVM for the female participants. The conclusion is that contrary to the authors' expectations, the male participants are more involved with, or more attached/attracted to, cricket-based scones.

This difference can be explained in three ways: first, the information regarding edible insects has received interests from the local media, but there is discrimination in accessing the media in favor of male households as reported by Okello et al. (2009) and Pambo et al. (2014). For instance, Pambo et al. (2014) reported that female households from rural areas in Kenya are on average 64% less likely to access food information (regarding fortification) from the media than their male-counterparts. Due to their dominance over media resources and given the attention that edible insects have recently received from the media (enumerated at the introduction section), the males possibly developed more interest, hence their higher involvement with cricket-scones. Therefore, we conclude that promoting insect-based products solely over the media would exclude female households, thus counteractive. Alternative avenues along the insect value-chain (such as, farmers, sellers, scientists/researchers, nutritionists) would be more successful. Second, the requirement to taste cricket-scones, which is unfamiliar product, probably stressed the females more than the male participants. Lind (2007) argued that participants in a stressful environment show less interest as they tend to "think", while in a calmer situation, participants tend to "feel" more and take their time to rationalize and linger over their decision. Third, the differences in male and female participants' involvement in cricket-scones could also be due to the sample size. The number of respondents might not have been large enough to compensate for the fact that they have different personalities, cognitive styles and other characteristics, which could have affected their HVMs.

5 Summary and Conclusions

The HVM for the whole sample shows that participants would consume cricket-based scones due to good taste, being perceived as nutritious as well as the ability to promote environmental responsibility. They would do so to be strong, which allows them to produce more food, be wealthy and earn more income to educate children, invest, and also meet other family needs. These benefits of consuming cricket-based scones, in turn enables the participants achieve three life goals (values) namely, long life, happiness and being secure. The challenge for the producers/marketers of insect-based foods is to link their products to life-goals that the consumer is willing to achieve, otherwise they will not be able to compete with the more-conventional alternatives.

For the male participants, the abstract characteristic "care for the environment" is very important. This suggests that some consumers are concerned with the production method when choosing what to consume. Cricket-based scones' marketers should therefore consider this when designing campaigns to promote consumption. The male participants were also more involved with cricket-based scones. Possibly, the female participants associated cricket-based scones with unfamiliar products. But, this gives marketing opportunities to producers because consumers who are less involved with a product would consume mainly for the functional-value, and their attitudes are normally unstable (Lind 2007; Barrena and Sánchez 2009). It is also a key policy tool for creating sustainable food systems to feed into the food and nutrition security equation. The implication is that shaping the perceptions and attitudes of the females in favor of insect-based products is relatively easier. Therefore, promoting consumption of cricket-based scones would be much easier among the female households, hence marketing strategies designed to target women would potentially bear more success.

Food marketers should use both motivational themes identified by this study while promoting consumption of insect-based foods (like cricket-scones). The focus has been on nutritional and economic benefits, in addition to environmental-conservation issues. But apparently, consumers perceive the sensory characteristics "sweet" (sugary), "taste" and "colour" to be more important. These results provide marketers with valuable campaign messages and slogans when designing marketing information. It specifically identifies three additional themes: that consumption of insect-based foods brings "happiness", "food security" and a "healthy life". These three additional themes can be used to promote mass rearing and consumption of insect-based foods to sustainably increase the supply of proteins in developing countries.

References

Alemu M, Olsen S, Vedel S, Kinyuru J, Pambo K (2017) Can insects increase food security in developing countries? An analysis of Kenyan consumer preferences and demand for cricket flour buns. Food Secur:1–14. https://doi.org/10.1007/s12571-017-0676-0

Arsil P, Li E, Bruwer J, Lyons G (2014) Exploring consumer motivations towards buying local fresh food products. Br Food J 116(10):1533–1549

Barrena R, Sánchez M (2009) Consumption frequency and degree of abstraction: a study using the laddering technique on beef consumers. Food Qual Prefer 20(2):144–155

Beardsworth A, Bryman A, Keil T, Goode J, Haslam C, Lancashire E (2002) Women, men and food: the significance of gender for nutritional attitudes and choices. Br Food J 104(7):470–491

Christensen D, Orech F, Mungai M, Larsen T, Friis H, Hansen J (2006) Entomophagy among the Luo of Kenya: a potential mineral source? Int J Food Sci Nutr 57(3/4):198–203

Crudge S, Johnson F (2007) Using the repertory grid and laddering technique to determine the user's evaluative model of search engines. J Doc 63(2):259–280

Grunert K, Grunert C (1995) Measuring subjective meaning structures by the laddering method: theoretical considerations and methodological problems. Int J Res Mark 12(3):209–225

ICCO (2013) Edible insect breeding in Kenya. ICCO—Inter Church Organization for Development Cooperation, representing an international Public Private Partnership; an established NGO based in the Netherlands. www.icco.nl. Accessed 11 Sep 2016

Kelly G (1955) A theory of personality – the psychology of personal constructs. W. W. Norton, New York

Lagerkvist C, Ngigi M, Okello J, Karanja N (2012) Means-end chain approach to understanding farmers' motivations for pesticide use in leafy vegetables: the case of kale in peri-urban Nairobi, Kenya. Crop Prot 39:72–80

Lensvelt E, Steenbekkers L (2014) Exploring consumer acceptance of entomophagy: a survey and experiment in Australia and the Netherlands. Ecol Food Nutr 53:543–561

Lind LW (2007) Consumer involvement and perceived differentiation of different kinds of pork – a means-end chain analysis. Food Qual Prefer 18:690–700

Münke-Svendsen C, Ekesi S, Ayieko M, Kinyuru J, Halloran A, Makkar H, Roos N (2016) Insects as food and feed in Kenya – past, current and future perspectives. Greeinsect Technical Brief No.1, Copenhagen, Denmark. http://greeinsect.ku.dk/publications-edible-insects-project/2016/

Okello J, Okello R, Ofwona-Adera E (2009) Awareness and use of mobile phones by smallholder farmers in Kenya. In: Maumbe BM (ed) E-agriculture and e-government for global policy development: implications and future directions. IGI Global, Amazon.com Eastern Kentucky University, USA

Okello J, Largerkvist C, Ngigi M, Karanja N (2013) Means-end chain analysis explains soil fertility management decisions by peri-urban vegetable growers in Kenya. Int J Agric Sustain 10:1–19

Olson J, Reynolds T (2001) The means-end approach to understanding consumer decision making. In: Reynolds T, Olson J (eds) Understanding consumer decision making – the means-end approach to marketing and advertising strategy. Lawrence Erlbaum Associates, Mahwah, NJ

Pambo K, Otieno D, Okello J (2014) Consumer awareness of food fortification in Kenya: The case of vitamin-A-fortified sugar. Paper presented at the International Food and Agribusiness Management Association (IFAMA) 24th annual world symposium, Cape Town, South Africa, June 16–17

Pambo K, Okello J, Mbeche R, Kinyuru J (2016) Consumer acceptance of edible insects for non-meat protein in western Kenya. Paper prepared for presentation at the 5th African Association of Agricultural Economists (AAAE) conference at the United Nations Conference Center, Addis Ababa-Ethiopia, September 23–26

Pambo K, Okello J, Mbeche R, Kinyuru J (2017) Exploring the influence of differentiated nutrition information on consumers' mental models regarding foods from edible insects: A means-end chain analysis. Ecol Food Nutr 56(6):530–551

Pambo K, Okello J, Mbeche R, Kinyuru J, Alemu M (2018) The role of product information on consumer sensory evaluation, expectations, experiences and emotions of cricket-flour-containing buns. Food Research International, doi.org/10.1016/j.foodres.2018.01.011

Pieters R, Baumgartner H, Allen D (1995) A means-end chain approach to consumer goal structures. Int J Res Mark 12(3):227–244

Reynolds T, Gutman J (1988) Laddering theory, method, analysis, and interpretation. J Advert Res 28(1):11–31

Schaefers T (2013) Exploring car-sharing usage motives: a hierarchical means-end chain analysis. Transp Res A Policy Pract 47:69–77

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

Zaichkowsky L (1985) Measuring the involvement construct. J Cons Res 12(3):341–352

Part VIII
Legislation and Policy on the Use of Insects as Food and Feed

PROteINSECT: Insects as a Sustainable Source of Protein

Elaine C. Fitches and Rhonda Smith

Abstract European awareness of the potential use of insects as a protein source for animal feed has grown rapidly in recent years. Interest has been driven by heavy European reliance on crop protein imports for feed, challenges associated with the increasing global demand for animal protein, and the recognition that certain insects can be grown at scale on relatively low value organic wastes. However, with limited historical use of insects as a protein source for feed in Europe, their use has, until recently, neither been required nor considered in European Union legislation. Here we describe how the European funded project PROteINSECT (www.proteinsect.eu) enabled scientists, insect farmers, communication experts, funding agencies, regulatory bodies and other stakeholders to collaborate to drive progress towards the safe and legal use of insect protein in animal feed. A 3-year research project, PROteINSECT investigated the potential use of dipteran larvae as a novel source of protein for feeding fish and monogastric livestock (pigs and poultry). Mounting scientific evidence, including that generated by PROteINSECT partners, building confidence in the safety, feasibility, and sustainability of commercial scale insect production, was met with a willingness of the regulatory authorities to begin to address the necessary legislative changes to enable the protein derived from certain insect species to be legally incorporated into feed. In the last year of the PROteINSECT project, clear evidence of progress emerged as changes in European legislation permitting the use of processed insect protein in aquaculture feed were anticipated to come into force in 2017.

E. C. Fitches (✉)
Department of Biosciences, University of Durham, Durham, UK

Fera Science Ltd, York, UK
e-mail: e.c.fitches@durham.ac.uk

R. Smith
Minerva Communications Ltd, Hampshire, UK

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_26

1 Rationale and Design of the PROteINSECT Project

Europe has been dependent for more than 40 years on the importation of 70–80% of its protein crop requirements, such as soya and maize, to supply quality feed for livestock production (Martin 2014). This, together with increased global demand for meat, fish and eggs (Robinson and Pozzi 2011), formed the basis for the European Parliament's adoption of a resolution to address the European Unions' (EU) protein deficit in 2011.Concomitant with growth in livestock production is the generation of increasing volumes of organic waste with the EU now producing as much as 88 million tonnes of food waste (Stenmarck et al. 2016) and 1.4 billion tonnes of manure (Lyngsø et al. 2011) every year.

On the back of the resolution to address Europe's protein deficit, the European Commission through its Seventh Framework Research Programme issued calls for proposals to drive knowledge forward with the aim of producing solutions to address that deficit. One of the calls – "Insects as novel sources of proteins" – recognised the use of insects in feed and food as offering potentially significant environmental, economic and food security benefits to Europe. It was to address this call that a consortium of partners, led by Fera Science in the UK, was created, developing the PROteINSECT project which successfully secured funding in 2013 for research focused primarily on the use of insect protein in animal feed.

1.1 Project Design

The PROteINSECT consortium is made up of 12 partners from 7 countries led by Fera Science Ltd. of the UK, with seven academic partners based in Africa, China, Belgium, Scotland and Switzerland, two industry partners in Belgium and the UK, and two small and medium sized enterprises (SMEs) based in Austria and the UK, experts in science communication and policy development. Full details of the partners can be found on the project website (www.proteinsect.eu).

The need to find novel sources of protein for animal feed, together with the opportunity presented by insects to both reduce volumes and derive value from organic waste were the driving forces behind the rationale and design of the PROteINSECT project. Its programme of work was organised across 5 key areas:

- The development and optimization of fly larvae production methods for use in both developed and developing countries at small and large scale
- Determination of safety and quality criteria for insect protein products.
- Evaluation of processing methodologies and the evaluation of crude and refined insect protein extracts in fish, chicken and pig feeding trials.
- The assessment of the optimal design of insect-based animal feed production systems utilising the results of a comprehensive life cycle analysis.
- Creation of a pro-insect platform in Europe to encourage discussion about, and ultimately adoption of, sustainable production technologies and to include examination of and debate around the regulatory framework.

The approach taken by the consortium was further underpinned by an amalgamation of fact and opinion. That certain insects can grow rapidly *en masse* on a range of "waste" products is well established and critically, insects are rich in protein and a natural component of the diets of carnivorous fish and free-range chickens. The ability of dipteran larvae to develop on a range of organic wastes led us to concentrate our research efforts on housefly (*Musca domestica*) and black soldier fly (*Hermetia illuscens*) (Barnard et al. 1998; Myers et al. 2008; Hwangbo et al. 2009; Yu et al. 2011; Čičková et al. 2012; Zhang et al. 2012; Oonincx et al. 2015; Zhu et al. 2015).

The project's focus on feed, rather than on insects for human food, was driven by the belief that western cultures, with little or no tradition of entomophagy, were unlikely to choose insects in preference to meat or fish to an extent that would result in a significant impact on the protein deficit. Furthermore, many insects suitable for mass production and direct consumption (e.g. mealworms, grasshoppers, crickets) develop on foodstuffs that are often already suitable for human consumption (e.g. wheat-bran) and, as such, it was thought that the potential for a net gain in food supply is limited. By contrast, flies that can be reared on low value wastes are generally considered repulsive by humans and, therefore, are not appropriate candidates for direct consumption.

At the time of assembling the consortium the mass rearing of insects in Europe for animal feed, other than for pet or bird feed, was a relatively new concept. As such, the need to draw on expertise from the continents of Asia and Africa, that have a history of insect farming, was clear. The willingness of PROteINSECT partner scientists in Africa and China to share their expertise and insects was key to the design of the project and these partners were instrumental in the delivery of the planned detailed work.

1.2 Nutrition Quality and Safety

As neither the nutritional value of insects, nor the safety of such protein sources, for animal feed, had been widely examined or documented in the literature, their use had neither been considered nor specified in EU legislation. PROteINSECT partners set out to fill these gaps to support consideration of their use.

Nutritional analyses were carried out in the UK, and in Belgium, to deliver a clearer understanding of the potential value of insects in the feed chain for fish, poultry and pigs. The analysis was designed to assess and record levels of protein and added value elements such as amino acid profiles in both house fly and black soldier fly larvae. Feeding trials incorporating insect meal for fish, pigs and poultry were carried out in the UK and Belgium to evaluate survival, growth rate, weight gain and to monitor any adverse reactions such as allergenicity.

Paramount to the use of any novel feed product is demonstration of its safety. An extensive screening programme was deemed essential to evaluate if insects reared on manures, which may contain a range of biological and chemical contaminants, could be safely incorporated into the feed and thus the human food chain (Charlton et al. 2015). This vital work was carried out in the UK by the PROteINSECT team at Fera Science Ltd.

1.3 DG Sante: A Key Stakeholder

Equally important to the research required was the need to communicate the vision and aims of the PROteINSECT project's research and its scientific rationale and findings not only with key stakeholders across the feed chain but also with the wider public. Therefore, the project's ultimate goal was to bring together scientists and communication experts in such a way as to allow the progression of discussion about and introduction of the safe exploitation of insects for feed from proof of principle to the marketplace.

The strategy deployed included engagement with the key body responsible for the implementation of EU laws on the safety of food and other products (including feed), on consumers' rights and on the protection of people's health. This body, now known as DG Sante (formerly DG Sanco), is the Director General of Food and Health Safety in the European Commission. Identifying and communicating with the key personnel responsible for the animal feed committee was an important strategic activity.

2 PROteINSECT Communication Strategy, Documents and Actions

To support the evolution of a positive and receptive platform in Europe for the use of insects in animal feed, PROteINSECT engaged with key external stakeholders from the onset of the project, creating a 'platform' through which debate and discussion could be encouraged and dissemination and communication activities channeled.

Engagement across the platform was planned in order to allow a consensus view to be formulated; this we believed would ensure that the path to legislation would be through common awareness rather than eccentric and/or subjective individual views. With virtually nothing known as to the level of acceptability of the use of insects in livestock diets to European consumers, it was vital that the project was able to both track consumer opinion and increase awareness.

2.1 Communication Timeline

Figure 1 provides a timeline for the production of four core project communication documents, together with external milestone events that helped to drive the progression of the concept of insects in feed towards their safe and approved use in feed. Core documents were supported by involvement in a wide range of media activities including managing social media, press releases, television and radio interviews, the production of two short documentary films promoted through the general and

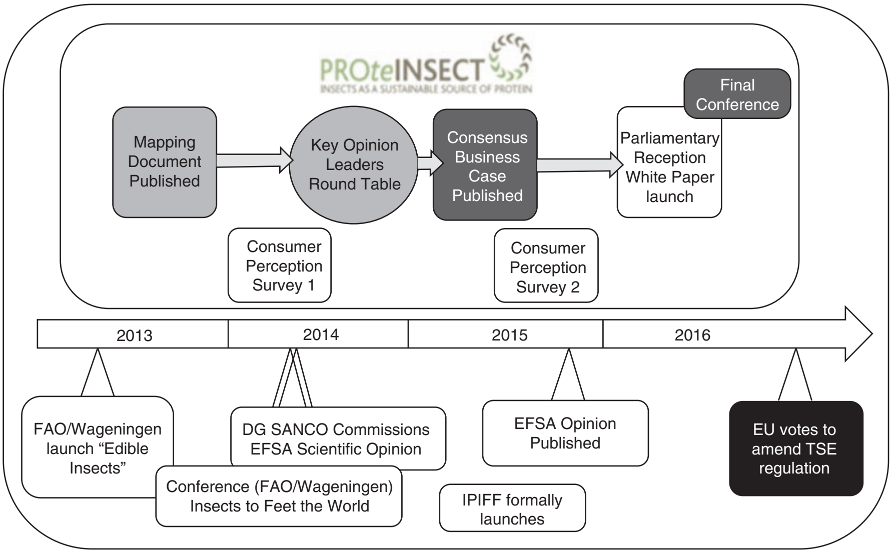


Fig. 1 Timeline of core PROteINSECT communication documents and external events that were key to progressing legislative changes necessary to enable the legal use of insects in animal feed

specialist media channels, and the hosting of a scientific conference. Careful consideration of project messages to the media ensured that claims about the potential benefits or risks of using insects in feed were not sensationalized.

Awareness of the potential use of insects in feed was further enhanced by the participation of project partners in more than 54 dissemination events including conferences, workshops and meetings across Europe, China and Africa. PROteINSECT consistently promoted the need to identify and address the knowledge gaps that must be filled to ensure the safe use of insects in the feed and thus food chain. This approach helped to lay an appropriate foundation to help the wider public, as well as interested parties, make an informed decision about the acceptability of the introduction and use of insect protein in the feed chain.

2.2 *Stakeholder Engagement*

The first key communication document produced was a mapping report of relevant European regulation, legislation and policies. This document provided a review of legislation specific to the mass rearing of insects and their use in feed and food and highlighted the need to provide robust scientific evidence for the safe use of insects in feed and food (PROteINSECT et al. 2013).

Figure 2 provides an overview of target areas for legislation that were highlighted in the mapping document; this together with position papers tailored to individual stakeholder groups, provided key reference documents for subsequent

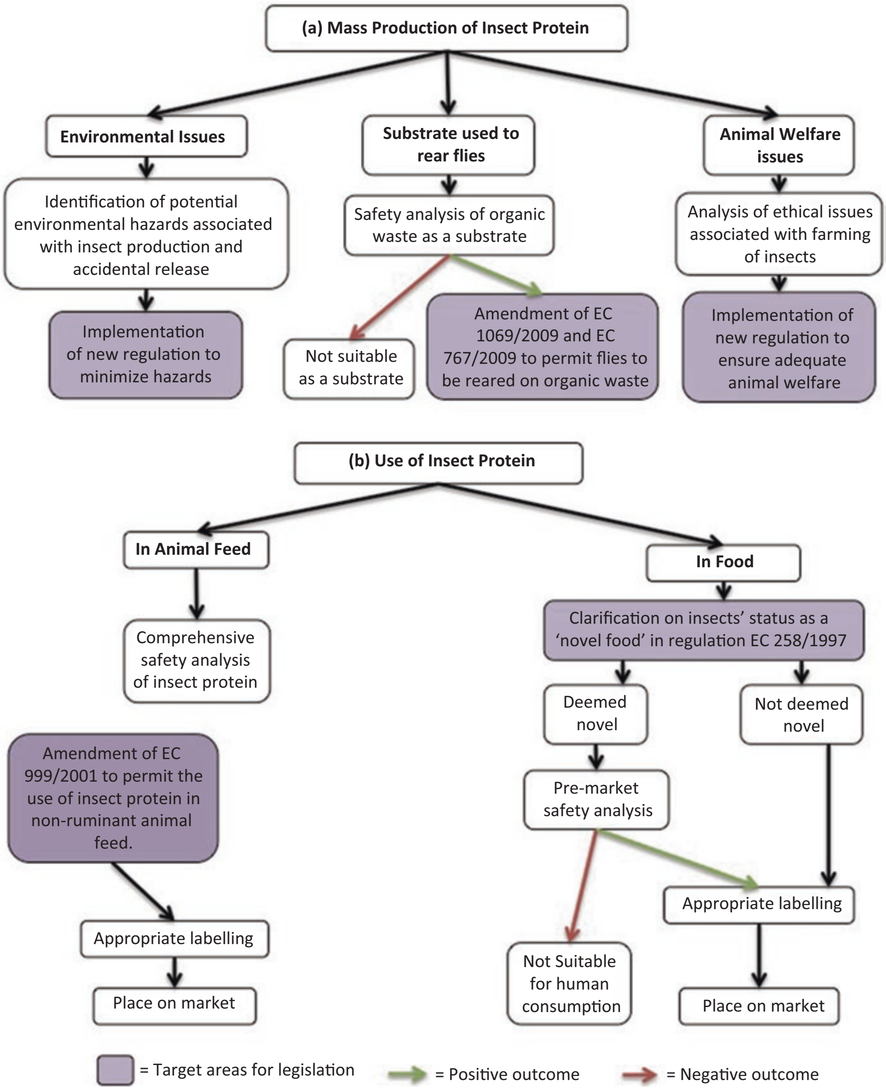


Fig. 2 Target areas for legislation: (**a**) Mass Production of Insect Protein (**b**) Use of Insect Protein (Reproduced from PROteINSECT's Mapping Legislation Report (2013))

discussion during a Key Opinion Leaders (KOL) Round Table event. The Round Table was attended by a range of stakeholders including policy makers (including the responsible officer from DG Sante), aquaculture producers, poultry and pig farmers, animal nutritionists, consumers, retailers, food certification bodies, feed producers and waste recycling experts. The outcomes of the Round Table were summarized in a report highlighting priority areas for the development of insect protein in Europe, such as the need for additional safety and quality data, and the importance of life cycle assessment for sustainable insect production.

A Consensus Business Case, officially endorsed by many of the organisations that contributed to it including DG Sante, was prepared based on the outcomes of the Round Table, plus contributions from attendees, other stakeholders who contributed via correspondence, and project partners, as well as a review of published research. The Business Case laid out the advantages of an additional insect based protein source for animal feed and highlighted key barriers to its adoption within Europe at scale. It was launched into the public domain via media communications and targeted social media activity and uploaded to the project website where it has been downloaded over 4000 times (PROteINSECT et al. 2015).

2.3 Insect Protein: Feed for the Future

Finally, at the end of the project, a White Paper entitled 'Insect Protein-Feed for the Future: addressing the need for feeds of the future today' (PROteINSECT et al. 2016) was officially launched at a Reception in the European Parliament with the sponsorship and support of Jan Huitema, Member of European Parliament (MEP) for the People's Party for Freedom and Democracy in The Netherlands, who is also a member of the Committee on Agriculture and Rural Development.

The launch of the White Paper was followed on the next day by the final PROteINSECT conference 'Insect Protein – Feed for the Future' also held in Brussels and attended by a global audience of 130 interested parties from research, policy, industry and the media. In addition to presentations by PROteINSECT project partners, invited speakers included Jan Huitema MEP, Paul Vantomme of the Food and Agricultural Organisation of the United Nations (FAO), Antoine Hubert, the president of the International Platform for Insects as Food and Feed (IPIFF) and Dr. Wolfgang Trunk, the responsible officer for animal feed within DG Sante. Conference material was subsequently complied into a Book of Proceedings and made publicly available on the project website (PROteINSECT 2016).

2.4 Consumer Attitudes

The adoption of insects into the feed chain is ultimately dependent on consumer attitudes towards the consumption of meat, fish and dairy products derived from animals fed on diets containing insect protein. As such, a further fundamental element of the communication strategy was to raise public awareness and to gauge the likely level of consumer acceptance of the use of insects in feed.

An initial benchmarking survey conducted in 2013 found a high level of support for the use of insects in feed; for example more than 70% of 1300 respondents stated they would eat fish, chicken or pork that had been fed on protein from insects.

Almost 90% of respondents to the first survey also thought that more information should be available on the use of insects as a food source for animals and humans. The second survey benchmarked consumer perceptions of the use of insects for animal feed as compared to conventional sources of feed protein. Again a high level of acceptability (70%) for insects in livestock feed was recorded from over 1000 respondents, with 64% believing that there was no or only low risk to human health in eating farmed animals that had been raised on diets containing insect meal.

3 The Impact of Research and Communication on Legislation

Recognition by the European Commission that the use of insects in feed and food could offer significant environmental, economic and food security benefits, evidenced by the research call through which PROteINSECT was funded, coincided with a landmark publication "Edible Insects: Future Prospects for Food and Feed Security" published by the FAO in 2013 (van Huis et al. 2013). This publication was the first to highlight the lack of a legal framework as a major barrier to the adoption of insects as food and feed in Europe.

3.1 Significant Initiatives

National funding to support projects such as BioConVal (Conversion of chicken manure by fly larvae) in Denmark, DESIRABLE (DESigning the Insect bioRefinery to contribute to a more sustainABLE agrifood industry) in France, and Aquafly (investigating the potential of using insects as safe and healthy ingredients of future fish feeds) in Norway, provided further proof of European support for the concept. Also of significance was that three EU Member States, Belgium, France and the Netherlands performed risk assessments related to the use of insects as food or feed.

The "Insects to Feed the World" conference in The Netherlands in 2014, organized jointly by the FAO and Wageningen University, was a further milestone in the advancement of insects as a new frontier in Europe. A wide range of stakeholders, including academics, insect producers, animal feed producers as well as representatives of DG Sante were, for the first time, assembled under a single roof. The conference sparked the establishment in 2015 of a new Scientific Journal, the "Journal of Insects as Food and Feed" produced by Wageningen Academic Publishers.

This year also brought the official launch of the International Platform for Insects as Food and Feed (IPIFF), bringing together insect producing small and medium sized enterprises (SMEs) and start-up companies in Europe including Ynsect in France, Protix in Holland, and businesses such as Agriprotein in South Africa, and Entofood in Malaysia. IPIFF members are committed exclusively to using vegetal rearing substrates and are actively developing Hazard Analysis and Critical Control Points (HACCP) procedures to ensure insect food and feed is safe for consumption.

3.2 PROteINSECT: A Voice of Reason

Riding on the wave of the mounting evidence in support of the exploitation of insects for feed and food and with direct support from the European Commission, PROteINSECT partners were ideally positioned to engage directly with DG Sante.

As a research focused consortium, PROteINSECT was able to act as a "voice of reason"; providing data in support of the safe use of insects in the feed chain as well as cautionary messages, such as highlighting the need to consider the potential for allergenic reactions in people working in the insect producing industry. Prompted by the upsurge in research and development, the EC commissioned a European Food Safety Authority (EFSA) Scientific Committee to conduct a scientific assessment of the possible use of insects in feed and food. This risk profile, which was related to the production and consumption of insects as food and feed was based on data from peer-reviewed scientific literature, assessments performed by Member States and information provided by relevant stakeholders. PROteINSECT was a key contributor to the report that was published in October 2015 (EFSA 2015).

EFSA confirmed that, when currently allowed feed materials were used to feed insects, that the possible occurrence of microbiological hazards were expected to be comparable to other sources of protein of animal origin and thus should not pose any additional risk compared to other feed ingredients. The risk profile also highlighted the need for "further research for better assessment of microbiological and chemical risks from insects as food and feed including studies on the occurrence of hazards when using particular substrates, like food waste and manure." The growing body of scientific evidence, together with increasing consumer awareness and evidence of support appeared to be opening the legislative door.

4 Action by Policy Players and Industry

4.1 Progress in America and Canada

The lifting of legal barriers to allow insects to be used as animal feed in the Western world was pioneered in the US by the Food and Drug Administration (FDA) who in 2016 approved the use of black soldier fly (BSF) larvae in salmonid feed. This followed acceptance of an application to the Ingredients Definition Committee of the Association of American Feed Control Officials (AAFCO) made by the Canadian company Enterra based in Vancouver, who produce BSF reared on pre-consumer food waste. The Canadian Food Inspection Agency (CFIA) approved the use Enterra's BSF as a novel feed Ingredient in poultry feed in July 2016, following a 4-year assessment of the safety of the product. In addition to providing a new source of protein for animal feed the potential for insects to reduce "waste" is demonstrated by Enterra plans to process up to 54, 000 tonnes of pre-consumer waste annually. It is anticipated that this will make a significant contribution to helping food producers comply with Metro Vancouver's 2015 ban on the disposal of food as landfill.

4.2 Progress in Europe

In Europe, the EFSA opinion provided a basis for revision of the feed ban that currently prohibits the use of processed animal protein (PAP) from insects to be used in feed for farmed animals. DG Sante subsequently provided discussion documents to the Transmissible Spongiform Encephalopathy (TSE) and Animal By-Products (ABP) working groups (comprised of Member State Government representatives) outlining amendments to TSE, ABP and feed legislation that needed to be addressed in order to enable processed insect protein to be used in feed for aquaculture.

These documents explicitly state that general requirements for feed hygiene and animal health apply to insect production, and that insects may only be produced in Europe using substrates that are eligible as feed materials for farmed animals. This means that only former foodstuffs that do not contain meat or fish may be acceptable as insect rearing substrates. It was suggested that a list of insect species, based on those that are currently farmed in Europe (i.e. Black Soldier Fly, Yellow Mealworm *Tenebrio molitor*, Lesser Mealworm *Alphitobius diaperinus*, House cricket *Acheta domesticus*, Banded cricket *Gryllodes sigillatus* and Field Cricket *Gryllus assimilis*) be included in the Catalogue of Feed materials.

A formal vote to amend TSE Regulation 999/2001 was passed in a meeting of the EU Standing Committee on Plants, Animals, Food and Feed in December 2016. This is now under scrutiny by the European Council and Parliament and it is anticipated that new legislation permitting the use of insect PAP in aquaculture feed will come into force in the first half of 2017.

4.3 International Impact

Projected regulatory changes have opened the door for insect producing companies to expand on a global level. For example Agriprotein, one of the first insect producing companies to set up outside of Asia, has recently announced a 10 million dollar deal to set up 100 fly farms across the globe in collaboration with the engineering group Christof Industries. Agriprotein uses a blend of supermarket, restaurant and food and feed factory streams to rear BSF at scale. With an annual production potential of nearly 5000 tonnes of MagMeal™ and 2000 tonnes of MagOil™ for every farm, the opportunity for insect products to start making inroads into the global feed market is clear.

5 Concluding Remarks: Potential Future Shifts in Policy

With European legislation to allow processed insect protein to be used in feed for aquaculture on the horizon, there is little doubt that significant progress has been made towards realizing the potential of use of insects to alleviate the protein feed deficit in Europe. Advances have been facilitated by the combined efforts of organisations such as the FAO, together with scientists and communication experts funded by the European Commission through the PROteINSECT project and through national governments, together with a willingness, on the part of the regulatory authorities, to respond positively to evidence for the safe use to insects.

5.1 Authorization of Organic Wastes

Following the Canadian example, it is likely that future changes to legislation will enable insect protein to be used in poultry and pig diets, providing further opportunities for the wide scale adoption of insects in the feed chain. However, regulatory restriction of insect rearing substrates to former foodstuffs already used directly to feed livestock is likely to limit the scale of insect production in Europe. An estimated 5 million tonnes of former foodstuffs, thought to account for 50–80% of total the food waste, is processed and used directly for animal feed in Europe (Stenmarck et al. 2016). Competition between the livestock industry and insect producers for former foodstuffs may well drive price increases to such an extent that insect production in Europe becomes economically unviable.

Any expansion of EU regulations to allow substrates such as manures, to be used for insect rearing would require the commissioning of a further EFSA opinion. In the light of the devastating Bovine Spongiform Encephalopathy (BSE) crisis in the 1990s, it is envisaged that further relaxation of the feed regulations would require additional and significant investment in research to evaluate safety as well as further, more comprehensive, considerations of consumer acceptability.

5.2 Availability of Organic Wastes

In contrast to the situation in Europe, vast volumes of organic wastes from industries such as palm oil and sugar cane production in Latin America, Africa and Asia offer huge potential for exploitation as insect rearing residues. For example, with an estimated production of more than 20 million tonnes of palm oil, predominantly in Indonesia and Malaysia, comes an equivalent volume of empty fruit bunch "waste" (IFIF, accessed 2017). In addition to rearing substrate supplies, warmer climatic conditions in these regions of the world means that energy requirements for insect rearing are considerably lower than that required for year round production in Europe.

5.3 Consistent Supply at Scale

Poultry and fish feed now account for almost a half of the global 1 billion tonnes of animal feed produced annually, and this market is dominated by large companies with at least 100 firms producing in the region of 1 million tonnes of compound feed every year. In order for insects to be taken seriously by large feed producers it is essential that insect supply is consistent and at scale.

In conclusion, Europe may well find that it can significantly reduce its reliance on fishmeal and the importation of crop protein through partial replacement with insect protein.

However, Europe may also discover that i remains largely dependent on importation of this new source of animal feed protein from warmer climates. Nevertheless, providing that large scale insect rearing does indeed fulfill it's potential to deliver quality feed products at the million tonne scale, this is surely a significant step towards improving the global sustainability of food production.

Acknowledgement This chapter was written in the framework of the project PROteINSECT of the European Union's Seventh Framework Programme for research, technological development and demonstration (grant agreement no. 312084).

References

Barnard DR, Harms RS, Sloan DR (1998) Biodegradation of poultry manure by house fly (Diptera: Muscidae). Community Ecosyst Ecol 27(3):600–605.2

Charlton AJ, Dickinson M, Wakefield ME, Fitches E, Kenis M, Han R, Zhu F, Kone N, Grant M, Devic E, Bruggeman G, Prior R, Smith R (2015) Exploring the chemical safety of fly larvae as a source of protein for animal feed. J Insects Food Feed 1:7–16

Čičková H, Pastor B, Kozánek M, Martínez-Sánchez A, Rojo S, Takác P (2012) Biodegradation of pig manure by the housefly, *Musca domestica*: a viable ecological strategy for pig manure management. PLoS One 7:e32798

EFSA Scientific Committee (2015) Risk profile related to production and consumption of insects as food and feed. EFSA J 13(10):4257., 60 pp. https://doi.org/10.2903/j.efsa.2015.4257

Hwangbo J, Hong EC, Jang A, Kang HK, JS O, Kim BW, Park BS (2009) Utilization of house fly-maggots, a feed supplement in the production of broiler chickens. J Environ Biol 30(4):609–614

International Feed Industry Federation (IFIF). http://www.ifif.org/pages/t/Global+feed+production. Accessed Feb 2017

Lyngsø FH, Flotats X, Blasi AB, Palatsi J, Magri A, Schelde KM (2011) Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 138

Martin N (2014) What is the way forward for protein supply? The European perspective. OCL Oilseeds Fats Crops Lipids 21(4):D403. https://doi.org/10.1051/ocl/2014015

Myers HM, Tomberlin JK, Lambert BD, Kattes D (2008) Development of black soldier fly (Diptera: Stratiomyidae) larvae fed dairy manure. Environ Entomol 37:11–15

Oonincx DGAB, van Huis A, van Loon JJA (2015) Nutrient utilisation by black soldier flies fed with chicken, pig, or cow manure. J Insects Food Feed 1(2):131–139

PROteINSECT (2016) http://www.proteinsect.eu/fileadmin/user_upload/press/final-conf/Book_of_Proceedingsv1.pdf

PROteINSECT, Smith R, Pryor R (2013) Mapping Legislation Report. Public Deliverable 5.1
PROteINSECT, Smith R, Barnes E (2015) Consensus Business Case. Public Deliverable 5.2
PROteINSECT, Smith R, Barnes E (2016) Insect protein – feed for the future. White Paper
Robinson TP, Pozzi F (2011) Mapping supply and demand for animal-source foods to 2030, FAO, Animal Production and Health Working Paper. No. 2. Rome
Stenmarck Å, Jensen C, Quested T, Moates G (2016) Estimates of European food waste levels (2016) Fusions; Reducing food waste through social innovation
van Huis A, Itterbeeck V, Kluner H, Mertens E, Halloran A, Muir G, Vantomme P (2013) "Edible Insects; Future Prospects for food and feed security". FAO Forestry Paper 171. Wageningen UR, FAO
Yu G, Cheng P, Chen Y, Li Y, Yang Z, Chen Y, Tomberlin JK (2011) Inoculating Poultry Manure With Companion Bacteria Influences Growth and Development of Black Soldier Fly (Diptera: Stratiomyidae) Larvae. Environ Entomol 40(1):30Ð35. (2011). https://doi.org/10.1603/EN10126
Zhang Z, Wang H, Zhu J, Suneethi S, Zheng J (2012) Swine manure vermicomposting via housefly larvae (*Musca domestica*): the dynamics of biochemical and microbial features. Bioresour Technol 118:563–571
Zhu F-X, Yao Y-L, Wang S-J, R-G D, Wang W-P, Chen X-Y, Hong C-L, Qi B, Xue Z-Y, Yang H-Q (2015) Housefly maggot-treated composting as sustainable option for pig manure management. Waste Manag 35:62–67

Insects in Thailand: National Leadership and Regional Development, from Standards to Regulations Through Association

Nathan Preteseille, Anne Deguerry, Massimo Reverberi, and Thomas Weigel

Abstract While the insect as food and feed industry undergoes a worldwide evolution, even called "revolution", South-East Asia with its historical entomoculture leader Thailand, is also getting structured. From farm to table, the Good Agricultural Practises (GAP) constitute a first major evolution at the first step of the value chain. The sustainability of the latter however relies on its environment and opportunities. The Asian Food and Feed Insect Association (AFFIA) plays an important role to support the insect industry development. Moreover, in the context of an increasing food safety global concern, authorities are also having a key role.

From regulations to production standards, through a first association of researchers and companies, there are representative signs of regional development presented in this chapter, from farm to fork.

1 Edible Insect Regulation in South-East Asia, an Introduction

Cricket farming was first introduced in North Eastern Thailand almost twenty years ago by entomologists at Khon Kaen University. A rapid increase in a few years led to a report of 22 000 farms, now there are around 20 000 (Hanboonsong et al. 2013). Asian countries usually do not have a specific regulation for farming or selling edible insects. Insects are a common practice in terms of rearing and eating.

N. Preteseille (✉)
AETS Thailand, Asian Food and Feed Insect Association, Bangkok, Thailand
e-mail: nathan.preteseille@aets-consultants.com

A. Deguerry
Entofood, Kuala Lumpur, Malaysia

M. Reverberi
Bugsolutely, Asian Food and Feed Insect Association, Bangkok, Thailand

T. Weigel
Veterinarians without Borders Canada, Ottawa, ON, Canada

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_27

However, one of the first project examples regarding insects as food regulation appeared during the 17th FAO/WHO Codex Alimentarius Coordinating Committee for Asia (CCASIA) in November 2010. The Lao People's Democratic Republic (Lao PDR) delegation proposed to create a Codex food standard for human grade crickets. The Food and Agriculture Organization (FAO) has collaborated with the Laotian Ministry of Health (MoH) to set up this proposal for the Codex Committee. Several countries, among them, Cambodia, Thailand and Malaysia, supported the proposal. The Committee noted that insects are consumed in many countries and that there is a great potential and growing global interest for the utilization of insects as a food resource and generally supported the proposal. The Chairman concluded by saying that there was an interest in this standard and that it will be discussed more in detail at the next session of the CCASIA. The Committee agreed with the Lao PDR delegation proposal to lead an electronic working group to compile the data from other countries.

2 The GAP Approach and Its Development in Thailand

The concept of GAP evolved in the context of increasingly globalized food systems and related concerns about sustainability and consumer protection. According to FAO, 'GAP applies available knowledge to address environmental, economic and social sustainability for on-farm processes and post-production processes resulting in safe and healthy food and non-food agricultural products' (FAO 2003). There have been efforts by governments, NGOs, and the private sector to develop GAP codes, standards and regulations applicable at the international, national, and local level. As a result, a wide range of GAP schemes have been applied to various commodities with different compliance requirements. Underlying motivations range from meeting international trade and government regulations to convincing consumers of the quality of local products (FAO 2003).

In October 2016, representatives of the European Union (EU) highlighted pathways for exporting edible insects to the EU at a conference in Bangkok. During this conference, the National Bureau of Agricultural Commodity and Food Standard (ACFS) presented its plans to develop standards for Good Agricultural Practices (GAP) for cricket farming in Thailand, also with the clear objective of seizing new market opportunities for the Thai cricket farming sector by accessing the EU. For various other commodities, different GAP schemes are already applied in Thailand.

In 2004, the Thai government launched the voluntary Q-GAP certification scheme (Q referring to quality) for agricultural production as a measure to promote Thai food products in the national market, improve food safety and quality, and to increase the access to global food markets. The scheme is implemented under the Ministry of Agriculture and Commodities by ACFS as national accreditation body and with responsibility for developing standards, the Department of Agriculture (DOA) as national certification body, and the Department of Agricultural Extension (DOAE), which provides trainings and advice to producers. All services provided under Q-GAP, from training to certification, are free for the producers. In addition to the public Q-GAP, there are two main private GAP schemes for agricultural production in Thailand, namely ThaiGAP and GlobalGAP, which apply stricter certification standards (Wongprawmas et al. 2015).

As for other standards, the establishment of GAP standards for cricket farming follows a sequence of pre-determined steps which are listed below (Pongsapitch 2016; ACFS 2011):

1. Identification of the item to be standardized.
2. The Agricultural Standards Committee (ASC) appoints a Technical Committee (TC), which includes relevant stakeholders, such as scientists and experts, government officers, farmers and private sector companies.
3. The TC develops a draft standard.
4. The ASC reviews the draft standard and decides whether the standard is voluntary or mandatory.
5. Public hearing to invite comments on the draft standard from the relevant stakeholders.
6. Submission of the draft standard to ASC for further consideration.
7. Notification of World Trade Organization in case of a new mandatory standard.
8. Endorsement of standard by Minister of Agriculture and Commodities and declaration in Royal Gazette.

Critical control points for cricket farming standards could include the assessment of cricket housing, farm location, and farming equipment; farm management practices related to feed and water, egg collection and incubation, cricket pest protection, and production documentation and recording; as well as animal health management and sanitary and food safety measures during production harvesting, storing, and transportation, including farm worker hygiene, waste management, and cleaning protocols for farm and equipment (Pongsapitch 2016; Hanboonsong and Jamjanya 2016).

Once the GAP standards are set and the supporting infrastructure is operational, the regular implementation process for the Q-GAP scheme may be applied (Wongprawmas et al. 2015):

1. Interested cricket farmers apply for Q-GAP certification at the local Office of Agricultural Research and Development (OARD).
2. Upon approval by OARD, cricket farmers participate in trainings conducted by DOAE.
3. Cricket farmers commence production according to GAP standards under the supervision of DOA.
4. OARD carries out on-farm inspections and advises on necessary corrections due to non-compliance with the standards.
5. Upon compliance with the standards, the cricket farmer receives a GAP certificate which allows labelling the products with the certification mark.

The establishment of GAP standards for cricket farming can be considered as a significant milestone in the process of further developing the insect farming industry in Thailand. Certification at the farm level and beyond can improve consumer acceptance of insects and insect-based products, enhance food safety and quality, and increase economic opportunities for insect farmers and other actors along the value chain. Moreover, by putting such standards in place, the Thai government recognizes insects as important agricultural commodities and as part of traditional Thai diets. Despite these positive aspects, it remains to be seen whether Q-GAP certified crickets can gain access to international markets – especially EU and United States markets require higher GAP standards, such as GlobalGAP.

3 The Asian Food and Feed Insect Association (AFFIA) Works for the Entomoculture Industry Growth

AFFIA was created in 2016 in order to support the development the entomoculture industry in South-East Asia. This part explains how the association was created and developed since August 2016.

The gathering of insect entrepreneurs and researchers in the world was first strongly represented by the International Platform for Insects as Food and Feed (IPIFF) in Europe. There was a need for interaction in South-East Asia seeing a booming entomoculture industry. Despite the differences between ASEAN (Association of Southeast Asian Nations) countries, concerns were promptly lifted due to everyone's motivation and with the success of its launch in good hands, the AFFIA could represent the will for development by its members. AFFIA started through a first meeting at "Application Européenne de Technologies et de Services" (AETS) French consulting company in August 2016, where the name and a draft list of activities were established.

In September 2016, the AFFIA association website is launched, as a platform for visibility and exchange between members and the whole world. Statutes of the association are finalized. In October 2016 the IPIFF officially recognizes the AFFIA and two major events were held in the same month:

1. The Chef and the Bug: With the help of the Cordon Bleu French Culinary School in Bangkok, and the Bugs Café Restaurant in Siem Reap, three association members organized an educational diner in the Thai capital, for more than 75 curious participants. The event featured more than 8 recipes including silkworm, crickets, ants and even mealworms in different elaborated recipes, as a nice introduction of bugs to the plate of often reluctant Bangkok citizens. The event was supported by the delegation of the European Union to Thailand.
2. The European Union (EU) Novel Food Regulation and the Special Case of Insects, as mentioned in the above part on GAP, was organized following the Chef and the Bug: While in the EU, the insect as food industry is on a growing curve, regulators and policy makers have a key role in protecting the consumer health without preventing the market development. To this regard, the EU

updated its 258/97 Novel Food regulation in the 2283/2015 one. The latter enables countries with recorded historical safe consumption to highlight this point for faster and reduced application process. Insects and particularly crickets bring Thailand to this position, and the event aimed at clarifying the regulatory changes, as well as providing some general feedback on insects as food and feed. Several AFFIA members participated in the event, and the AFFIA coordinator was part of the organization.

In November–December 2016 the AFFIA Executive Committee was elected and deciding to meet on a monthly basis. It is formed by actors from Thailand, Malaysia and Indonesia, and has a balanced representation between feed and food representatives. The first meeting happened in Bangkok early December and helped to define further management procedures. Three AFFIA members also organized a short course for a week on insects as food and feed, in Kasetsart University, Bangkok. With more than 30 participants, activities went from farm visit to product tasting through presentations and debates.

In 2017, AFFIA sees a continuous growth, with the registration of more and more stakeholders in the region (15 members registered from 8 ASIAN countries early 2017). AFFIA helps to provide motivation through collaboration, where actors may not have been able to address a specific challenge. But also, it supports the sector promotion, by an increasing presence in Food and Feed events. A major step was the invitation of AFFIA to be part of the Thai working group “Market access of cricket products”. Under order 8/2560, the National Bureau of Agricultural Commodities and Food Standards-ACFS- invited AFFIA to provide a representative to the Working Group, which has for first priority to assess the opportunities given by the EU Novel Food regulation 2015/2287 for Thailand. The AFFIA coordinator was designated to take the AFFIA chair at the Working Group, among 12 members, from universities to governmental bodies. The Working Group started February 2017. In parallel to the Working Group, ACFS is developing Good Agricultural Practises- GAP- for cricket farms (see above), filling in the safety GAP in the cricket production chain. To this regard, and as AFFIA is recognized as a speaker for several entomoculture stakeholders in Thailand, the draft GAP in Thai were shared well ahead of a Public hearing session in March 2017.

4 AFFIA and the Insect as Feed Industry

With an historical presence of the insect as food industry especially in Thailand, the majority of members are working on insects as food. However, as South-East Asia is a major actor in the feed sector and especially aquaculture with almost 90% of the worldwide production (FAO 2014) and as food waste management is known to be a growing challenge (Verstappen et al. 2016), insects as feed and their related applications see an increasing number of players.

While in Asia, the insect as feed regulation does not exist, there are recent evolutions in the EU that could be applied. Below is presented the state of the art insect-as-feed regulation and an EU-Asian comparison with moving forward recommendations

As is often the case in an emerging industry, self-regulation by the insect stakeholders in the industry is fostering the development of standards, codes of best practices and product quality metrics to raise credibility.

4.1 Feed Regulation in Europe

Following the crisis due to the Bovine Spongiform Encephalopathy (BSE) in the 1990s in the EU, there is a specific attention given to the animal feed substrate and the related regulations, which, in the case of insects, are defined as following (Halloran 2014):

- Dealing with health rules so as to ensure a high level of health and safety;
- Setting out the measures to be implemented for the processing of animal by-products;
- Establishing a classification of animal by-product materials;
- Listing undesirable substances, for which it sets limit values above which their presence in animal feeds is forbidden;
- Guaranteeing a high level of protection for animal health and welfare, as well as public health
- Establishing general rules governing feed hygiene, conditions and arrangements ensuring traceability of feed as well as conditions and arrangements for registrations and approval of establishments
- Establishing rules for the prevention, control and eradiation of certain transmissible spongiform encephalopathies in animals in order to protect human and animal health.

Until December 2016, EU regulation did not make the necessary distinction between insects and other non-ruminant animal feed. It has just recently evolved and it is a major regulatory development for the insect sector. Then, insect proteins should be authorised in Europe for use in aquaculture feed as from July 2017. Before that, if purified insect fat and hydrolysed insect proteins have been allowed as feed for livestock, non-hydrolysed insect proteins and insect fat could only be commercialized as pet food. Still, under the EC regulation 1069/2009, farmed animals intended for animal feeding can only be reared on 100% vegetables and/or eggs and dairy products (EC regulation 999/2001; EC regulation 1069/2009; EC regulation 142/2011). This limits considerably the list of substrates that can be used to produce insects and excludes most evident waste streams and access to circular economy virtuous circle.

4.2 Feed Regulation in ASIAN

In most of the ASIAN countries, except China where insect meal and defatted insect powder are both listed in the Feed Materials Catalogue as suitable animal feed ingredients, there is a lack of legislation around the use of insect in animal feed. Then ASIAN "insect as feed" producers have to deal with authorities and explore their national regulatory framework in order to find a way to use the existing regulation and stretch the frame to fit with insects.

The development of private standards by private companies might help in the development of national or regional standards. Lobby groups, such as AFFIA in the ASIAN region, have an essential role to play in the status of insects as feed and food in the region. We can currently identify two opposing movements; the EU and the ASIAN, in the case of insects. The first starts from a very strict regulatory framework and is recently gaining some flexibility for entomoculture, while the second shows an absence of legal framework. However, shared goals are leading all actors of the value chain to look at a broad range of regulatory areas, including feed standards in term of quality, biosecurity, traceability, standards, risk management and protection of the environment, as well as biodiversity. The world feed market being global; the feed regulations all over the world have to move accordingly.

5 Conclusion and Recommendations

South-east Asia (SEA) and especially Thailand constitute one of the cradles of the insect industry. However, while historically active in entomoculture, regulations are still not developed to match the need of the industry both for food and feed applications, which remains overlooked compared to other animal farming industry, sometimes even more than in European Countries where the last decade showed a lot of development.

But with a long-time experience of production and consumption, SEA countries are not going to leave the chance to take their part in a more and more globalized industry. And AFFIA is here to support them.

Whereas the association can really be considered as a new-born one, its development and recognition have been growing fast, with an already mutual recognition with international organization such as IPIFF, and also the French "Fédération Française des Producteurs, Importateurs et Distributeurs d'Insectes" (FFPIDI)- or the Journal of Insects as Food and Feed (JIFF). Very encouraging and motivating, we can be confident in the further growth of the association and its relevance in supporting the entomoculture industry.

References

ACFS (2011) The Agricultural Standards Act B.E. 2551 (2008). http://www.acfs.go.th/eng/standard_act.php Accessed 15 Dec 2016

FAO (2003) Development of a framework for Good Agricultural Practices. http://www.fao.org/docrep/meeting/006/y8704e.htm . Accessed 07 Mar 2017

FAO (2014) The state of world fisheries and aquaculture. Accessed 16 Sept 2017

Halloran A (2014) Discussion paper: regulatory frameworks influencing insects as food and feed. http://www.fao.org/edible-insects/39620-04ee142dbb758d9a521c619f31e28b004.pdf. Accessed 15 Dec 2016

Hanboonsong Y, Jamjanya T, Durst PB (eds) (2013) Six-legged livestock: edible insect farming, collection and marketing in Thailand. Food and Agriculture Organization. Available at: http://www.fao.org/docrep/017/i3246e/i3246e.pdf. Accessed 14 Dec 2016

Hanboonsong Y, Jamjanya T (2016) Cricket farming and GAP in Thailand. http://affia.org/wp-content/uploads/2016/11/Cricket-GAP-%E0%B8%AD.%E0%B8%A2%E0%B8%B8%E0%B8%9E%E0%B8%B2.pdf. Accessed 15 Dec 2016

Pongsapitch P (2016) GAP on cricket farming and market access to the EU. Paper presented at the conference The EU novel food regulation and the special case of insects, Bangkok, 26 Oct 2016

Verstappen BM , Pawa FF, Dortmans B, Bagastyo AY, Pratono AH, Rahmani P, Zurbrügg Ch (2016) Market driven upcycling of urban organic waste in Indonesia. Accessed 16 Sept 2017

Wongprawmas R, Canavari M, Waisarayutt C (2015) Food safety assurance system for fresh produce production in Thailand: a review. Qual Assur Saf Crops Foods 7(1):73–88. https://doi.org/10.3920/QAS2013.0255

The Effects of Regulation, Legislation and Policy on Consumption of Edible Insects in the Global South

Dana Elisabeth Wilderspin and Afton Halloran

Abstract With an expanding edible insect industry, regulators, legislators, and policy-makers face increasingly difficult decisions regarding trade, production, harvesting, and consumption. It is becoming clearer that no panacea or one-size-fits-all solutions exist for regulating the industry, and that solutions regarding a formal or informal economy must be tailored to each country and culture. If the edible insect industry is to expand, and if insects are to be a sustainable protein source in the future, it is crucial that the effects of current legal measures are mapped out. This will lay the foundation for creating future solutions, taking food safety, environmental sustainability, and consumer acceptance into consideration. Exploring how informal solutions, or a lack of legal measures, can end up advancing an industry or economy will also be an important tool in making the insect industry successful and sustainable. Lastly, it is imperative to understand that the consequences of both sensationalizing and alienating the consumption of edible insects, especially in a legal context, might impact not just the citizens of the Global North, but also the attitudes, and hence consumption behaviors, of those in the Global South.

1 Introduction

The extent and potential of the insect food industry has largely been overlooked by policy-makers (Hanboonsong et al. 2013). Likewise, the economic value of insects and the environmental impact of wild-harvested insects are areas that have largely been left unstudied (Meyer-Rochow et al. 2008). Understanding the effects of regulations, legislation, and policies (RLP) on edible insects – including their trade, harvesting, and consumption – is critical if edible insects are to be a significant and

D. E. Wilderspin (✉) · A. Halloran
Department of Nutrition, Exercise and Sports, Faculty of Science, University of Copenhagen, Copenhagen, Denmark

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_28

Fig. 1 A conceptual diagram demonstrating how regulations, legislation, and policies affect and are affected by a wide array of topics (Adapted from the Australasian Promotional Products Association [APPA], 2011)

sustainable food of the future. Likewise, mapping the effects RLP have – and will have – on farmers, wild-harvesters of insects, environmental sustainability, businesses, entrepreneurs, and consumers, is also vital for the continuation of the industry, whether formal or informal.

RLP, in general, are important elements of human society, providing guidance on how to act. RLP govern how insects are produced or gathered, processed, distributed, purchased, and consumed. RLP are also an important part of laying the foundation for increased consumption, consumer acceptance, and food safety – among other things. Moreover, it is equally important to review the positive and negative effects that current RLP have had, as well as the impact of when RLP are lacking.

In this chapter, we touch upon an array of topics such as environmental, economic, and social sustainability, as well as the interplay between them (Fig. 1). This systematic review asks how regulations, legislation and policies – and the lack thereof – influence the consumption of edible insects in the Global South. Furthermore, a number of sub-questions have been developed to explore this question further: (i) who benefits from regulations, legislation, and/or policies – and why?; (ii) who benefits from an informal economy – and why?; (iii) how do RLP – and the lack thereof – affect the habitats of the edible insects, and what repercussions follow?; and lastly (iv) do RLP – and the lack thereof – affect the consumption of edible insects, and if so, how?

1.1 Terminology

Several contested words and terms are used in this chapter, and it is therefore important to clarify their uses. 'Western' (and 'Westernization') are only used when quoting the works of other scholars or researchers, and the term 'Global North' is used instead, whenever possible. Likewise, the "Global South' will be used instead of 'Non-Western' and 'Third World'. While still contentious, we prefer this terminology as these terms are less Eurocentric and loaded. The same is the case with the term 'entomophagy,' which is described in the study by Evans et al. (2015) as an ambiguous terminology. Instead, the words 'insect-eating' or 'eating insects' are used in this chapter, when possible. While we acknowledge the differences between the terms regulation, legislation, and policy, they have similar functions, and therefore effects. As such, we use and refer to them collectively by their abbreviation 'RLP'. Lastly, the terms 'wild-harvest(er)', 'harvest(er)' and 'collect(or)' are used interchangeably.

1.2 Focus and Exclusions

Of the themes shown in Fig. 1, the focus will be on national (or governmental) RLP, consumer acceptance, and environmental sustainability in the Global South. We will not go into depth with the latter – regarding carbon footprints. The focus will be on insects as food – not as feed, medicine, an agricultural pest, or as a form of integrated pest management. Due to a limited amount of literature on how RLP affect consumption, consumer acceptance and food safety have been chosen as indicators of how consumption might be affected in the future.

The focus will be on the Global South; however, much of the available literature is from the Global North. Consequently, many of the points of view will be from the Global North. As will be shown in the literature review, there is a correlation between attitudes and acceptance of edible insects in the Global North, and the consumption in the Global South. Therefore, it is important to include the perspectives of the Global North.

2 Methodology

2.1 Overview of the Systematic Literature Search Process

A systematic literature review was carried out in July 2016, by using Web of Science (hereafter WoS), including Medline, and Google Scholar (hereafter GS). The aim of the literature search in GS was to find additional, relevant articles that did not show up in the WoS search engine. No limitation was set with regards to a time range.

2.2 Criteria for Inclusion and Exclusion

After selecting the 68 articles identified through the searches in GS and WoS, a preliminary exclusion process was initiated: in each article, the words "polic*", "regulat*" and "legislat*" were searched for. The articles had to contain at least one of these words, or variations of the words. Those which merely mentioned the need for RLP, without further addressing any one of these, were excluded. Only research papers and reports from peer-reviewed journals written in English were included, thereby excluding, for example, editorials. Some 'grey literature', such as books or reports from the United Nations Food and Agriculture Organization (FAO) were, however, included due to the lack of peer-reviewed articles on the given subject. The FAO reports were also included due to their significant impact on the discourse, and the fact that many countries depend on the FAO for information on which they base their own standards or national dietary guidelines (Halloran et al. 2015). After the exclusion process, a total of 33 studies or papers were included, and the reoccurring themes of this literature will be discussed in detail below.

2.3 Literature Review

The review covers four major themes, in the following order: (1) food safety; (2) consumer acceptance and nature conservation; (3) sustainability of farmed and wild-harvested insects, and (4) governmental involvement and traditional regulatory mechanisms.

2.3.1 Food Safety

When reviewing the literature on edible insect RLP, it quickly becomes apparent that authors from the Global North most often focus on food safety and consumer protection. Authors from the Global South, or papers about the Global South, mostly focus on environmental sustainability instead. This is due, in part, to the fact that conservation of wild species has been more of a priority in relation to RLP in countries where insects have been a traditional part of the diet (Halloran et al. 2015). This is confirmed by Laurenza and Carreño (2015) and Gorham (1979) in stating that where insect-eating is rare, the basis of legislation is related to the contamination of food and the perceived issues regarding health that are associated with insects in our food. While many populations in countries around the world have eaten insects for centuries, there are few examples of national regulations that include insects for human consumption (Halloran et al. 2015).

Kenya and Thailand are two such examples: in Kenya, insects are acknowledged in the National Guidelines on Nutrition and HIV/AIDS (Halloran et al. 2015), and in Thailand, a specific Good Agricultural Practices (GAP) standard is currently being developed. This GAP standard encompasses the whole value chain of the cricket farming process, including location, quality management, harvesting, storage, hygiene, and sanitation. Therefore, it is less of a surprise that many countries in the Global North, where insect-eating is not as widespread, have not paid attention to national legislation until very recently (Grabowski et al. 2016). There are some EU member states, such as Finland and Germany that have prohibited the marketing and commercial production of insects (Lähteenmäki-Uutela and Grmelová 2016). Others, like the Czech Republic, allow insect farming and marketing, but do not have any specific legal framework (Ibid.). Countries such as the UK (MacEvilly 2000) and the USA (Gorham 1979) have regulations regarding insects in food products (as a perceived contaminant), though insects are not explicitly mentioned as a source of food in any of their regulations (Laurenza and Carreño 2015). Within the Global North, edible insect products are currently sold and consumed in Belgium, France, UK, the Netherlands, and Canada (Halloran et al. 2015), for example, along with the USA (Ramaswamy 2015). However, the implementation of the new Novel Food Legislation will change the production and consumption of insects in the EU in 2018. Likewise, RLP are currently being developed in other countries in the Global North.

In order for the lack of RLP, as well as the ones already set in place, to not become barriers for production and consumption, especially in the Global South, we need precise legislation that encompasses insects as food, including labelling, standards, and other regulatory mechanisms that govern how the edible insects are produced, traded, and used (Halloran and Magid 2013; Kelemu et al. 2015). According to Kelemu et al. (2015:113), this may prove to be an uphill struggle, due to the current political environment and the lack of "international dialogue regarding the incorporation of insects as food and feed into international standards, such as the Codex [Alimentarius]" (CA).

An interesting paradox occurs in countries where eating insects is commonplace. Often, these countries do not have specific standards regarding insects as food, and therefore treat insects like any other food product (Halloran et al. 2015). In Thailand, for example, along with the greater region of South East Asia, there is a long tradition of insect consumption. Consequently, the region as a whole has perceived insect-related food safety to be no different than other food products. However, according to Gjerris et al. (2016:103) "consumer safety is key to consumer interest". In fact, the lack of RLP in this part of the Global South does not seem to have hindered consumption, and may have even been beneficial – as will be discussed later.

2.3.2 Consumer Acceptance and Nature Conservation

Like Yen (2015a) and Gjerris et al. (2016), Glover and Sexton (2015) state that consumer acceptance of edible insects, to a large extent, hinges on food safety and RLP. They argue that if consumers cannot be persuaded to try food made with insects, let alone incorporate them into a regular diet, eating insects will not become mainstream. As will be discussed later, a negative attitude to insect consumption in the Global North has already had a detrimental impact on consumption in parts of the Global South, which is why one cannot merely focus on the consumer acceptance in this region of the world. However, according to Halloran et al. (2017), emphasizing RLP that focus only on food security and environmental sustainability instead of palatability and flavour, is often removed from what the average consumer is looking for in a new product. Glover and Sexton (2015) seemingly agree, stating that the edible insect industry, along with its regulators, must demonstrate that besides being safe and sustainable, foods made out of insects can be nutritious, ethical, and palatable. Furthermore, these foods must be produced in large enough quantities for them to be affordable and have an impact on global food systems (Ibid.).

Regulators, legislators, and policymakers must act swiftly to achieve this goal, according to Glover and Sexton (2015). On the other hand, the authors also warn that one should not act too swiftly to avoid invoking any suspicion with the consumers that the regulators and industry are taking unnecessary risks in terms of food safety and quality. This might cause a deterioration of the public's trust in the regulations, similar to what added to the pervasive rejection of transgenic food crops in Europe (Ibid.). According to Yen (2015a) and van Huis (2013), this would contribute to one of the greatest barriers to success and expansion of the edible insect industry, which is the reluctance to eat insects. They both state that this reluctance, or "disgust factor" as Ramaswamy (2015:175) calls it, is due to the increasing influence of the Global North on food habits in the Global South, as well as the globalization of fast foods (Yen 2015a; van Huis 2013).

Yen (2015b) and Costa-Neto (2015) agree by adding that in the past, colonial powers also directly discouraged indigenous people of other countries or regions (Zambia and Latin America respectively, in this case) from eating insects, which has led to a loss of traditional knowledge, negatively affecting consumption, as well as surveillance of harvesting. Schabel (2010) challenges this, suggesting that a greater acceptance, and hence demand and consumption of insects might not purely be beneficial, and might also ironically lead to degradation of sustainable harvesting. According to Schabel (2010), a greater demand jeopardizes more traditional ways of extracting edible insects, turning it into a potential liability. This will lead to an even more critical need for regulation and management of forest habitats and the harvesting of insects.

2.3.3 Sustainability of Farmed and Wild-Harvested Insects

Wild-Harvested Insects

Whether edible insects can be sustainably and safely harvested from the wild is highly debated in the literature. First of all, Halloran and Magid (2013) state that there is little formal legislation governing the sustainability of edible insect harvesting. This is a crucial problem, seeing as the vast majority of edible insects to date are still estimated to be wild-harvested (Rumpold and Schlüter 2014).

According to Ramos-Elorduy (2006), some of the most important drivers of unsustainable harvesting in e.g. Mexico, are unqualified, non-native, independent workers. This is similar to Balinga et al. (2004), who state that the increasing number of collectors is one of the main causes of caterpillar overexploitation in Central and Southern Africa. This is due to collectors having to compete in supplying a growing and lucrative international trade within an eroded and informal framework of traditional and regulatory authority (Ibid.). However, the FAO Forestry Department (2004) claim that it is not certain as to whether overharvesting, or damage to habitats, is the prevailing threat. They also suggest that the damage may not even be associated with harvesting insects intended for food (Ibid.). This uncertainty jeopardizes the edible insect industry, because it may make it harder for governments to develop appropriate RLP. Furthermore, it is "conspicuous and surprising," as Schabel (2010:50) puts it, that foresters have generally been left out of relevant discussions regarding edible insects, despite most edible insects currently being found and informally harvested in the forest ecosystems. Equally surprising is the lack of references in academic literature dedicated to RLP regarding edible insects, except when referring to certain parts of Africa, where the sustainability of those resources is already at stake (Schabel 2010), such as Southern Africa, where edible insects are a vital protein source (Akpalu et al. 2009).

Insect Farming

The question is then whether farming the insects is a more viable option, which is a highly debated topic in the literature: Rumpold and Schlüter (2014) state that besides concerns regarding environmental issues, such as biodiversity and overexploitation, insect-rearing is preferred to wild-harvesting. This, they argue, is the safest and most controlled way to ensure food safety. However, the authors do not mention what consequences this might have for those who collect insects for a living and who might not have any other options for generating a livelihood. This further increases the need for decision-makers to consider the multi-dimensionality of insects as food, and fully understand the dynamics and drivers that influence the harvest, production, processing, trade, and sale of insects, as noted by Halloran et al. (2015).

Yen (2009) states that farming could be a possible means of helping to conserve wild populations and prevent them from overexploitation. Gjerris et al. (2016) are more critical, stating that the only way insects can become a sustainable animal protein is to mass-produce them (from which the topic of ethics also arises), essentially turning them into what Paoletti (2005) calls 'mini-livestock.' Van Huis (2013) argues, however, that at least certain insect species, such as crickets, can alleviate problems concerning organic waste disposal by raising them on waste streams unfit for human consumption. According to Halloran et al. (2017) and the European Food Safety Authority (EFSA) Scientific Committee (2015), however, this is increasingly contested and is a core issue concerning the development of RLP in Europe.

Likewise, a more regulated and intensive form of farming insects can ironically also lead to problems with both the environment and food safety (Hanboonsong et al. 2013; Halloran et al. 2017). Conversely, Yen (2015a:39) states that "farming may adversely affect local livelihoods unless they are locally based small-scale enterprises." Similarly, a disadvantage of any type of farming, no matter the scale, is the potential for the exotic species that have been introduced to escape into the local environment, establish, and wreak havoc on the natural ecosystem (Yen 2015a). The starkest statement comes from Niassy et al. (2016:164), who state that "wild harvesting is not sustainable". However, other scholars have challenged this assumption, which will be discussed later in this chapter.

Another important issue, according to Yhoung-Aree and Viwatpanich (2005), though barely mentioned in the literature, is how wild-harvested insects are more popular in the regions where they have been traditionally consumed. This is due to size and perceived taste and health differences, compared to farmed insects, hence making them more expensive (Ibid.). No RLP could change this, only modified technology that would make farmed insects resemble those that have been harvested from their natural environment (Ibid.). However, according to Hanboonsong et al. (2013:x) "as insect farming is promoted and management techniques are developed and adopted, less collection of wild insects will occur".

It is therefore evident that neither insect farming nor wild-harvesting is a panacea. However, with the inevitable industrialization of insect production, RLP that protect the insects' natural habitats must be made – if nothing else as a safety net and a source of renewal (Yen 2015a).

2.3.4 Governmental Involvement and Traditional Regulatory Mechanisms

The Effects of Informal RLP

Scholars disagree on whether or not the development of RLP is beneficial and how they should be implemented. According to Akpalu et al. (2009), many of the previously mentioned problems with unsustainable harvesting, especially in southern African countries such as Namibia and Botswana, are caused by the governments allowing communities to self-govern and self-regulate with traditional policies that are insufficient. Likewise, they also mention issues with local corruption and weak law enforcement. On the opposite end of the spectrum are Durst and Hanboonsong (2015) and Syampungani et al. (2009), explaining why it is problematic when the local leaders are taken out of the equation. They mention reasons such as internal power struggles within the government, the removal of functions and responsibilities of traditional leadership, along with policies that have emphasized the non-consumptive usage of protected resources. Two authors, Yen (2009) and Gahukar (2011), refer to a prime example of how traditional regulation can lead to sustainable harvesting, namely the Basi people of Zambia, who were first mentioned in an article by Mbata et al. (2002). This study describes how the Zambian government, unfortunately, did not recognize the Bisa people's system of regulations for sustainable harvesting. This undermined the informal regulations already set in place by not supporting the traditional penalties when rules were broken. This case supports Yen (2015a), who asserts that a set of guidelines which involve the local community is a superior way of enforcing a license or regulatory system. An exception, Yen adds, could be a type of certification if the seller benefits through selling a product (Ibid.).

The Effects of Governmental Involvement

Ramos-Elorduy (2006) argue that formal, governmental regulations are required to stop overexploitation. Gahukar (2011) exemplifies this, by describing tribal communities who, despite their efforts, need subsidies or financial incentives from the government for conserving natural resources. Halloran et al. (2015) agree, stating that in order to govern the sector, it is essential to have the government involved in the facilitation and development of appropriate RLP. Several other studies also explain why the government needs to play an active, positive role in promoting the research and consumption of edible insects (Pascucci and De-Magistris 2013; Halloran et al. 2017; Hanboonsong et al. 2013).

Lastly, Gahukar (2011) notes that governments should be in charge of facilitating food security and enabling insects for human consumption to develop as an industry. As mentioned, it is vital that the government plays a positive role, meaning one that does not end up crippling the edible insect industry. An example of negative governmental involvement is when a country's government does not regard insects as a food at all, which means that no regulations regarding the exploitation of natural populations will be made (Halloran et al. 2015). This can undermine both economic development and recognition of traditional food systems (Ibid.). Hanboonsong et al. (2013) add to the argument, stating that inadequate governmental involvement regarding RLP in the industry is a great weakness. According to Halloran et al. (2017), political will is an important element when regulations are introduced and maintained. However, national political will is not enough if suggestions for RLP are not ratified internationally.

Conversely, Halloran et al. (2017) likewise note how a lack of governmental involvement can also be beneficial for the local population. The development of RLP can be a time consuming and costly affair, which means that in some cases decision makers abstain from intervening in the informal economy (Halloran et al. 2017). In some cases, this may have caused the industry to prosper and develop, generating growth and reducing poverty (Halloran et al. 2015). Though, as more regulations concerning the livelihood of cricket farmers in Thailand, for example, are developed, it is unavoidable that they will become progressively affected by RLP (Halloran et al. 2017). According to Schabel (2010:58), the RLP that are made with regards to "insect extraction must be fine-tuned to decide who gets a license, where and when to collect, what stage of insect is legal to collect, how many can be collected and by what mode". This will help to ensure a suitable balance between incentives and enforcement, along with social and financial equitability (Ibid.). Yen (2015a), however, states that a considerable amount of the insects that are consumed or traded in Thailand have come from across its borders, making it nearly impossible for governments to fully enforce such rules or regulation. He adds that even within the country itself, the extent and nature of the trade and production vary considerably (Ibid.), further complicating the case.

3 Conclusion and Recommendations

3.1 Benefits of Informality

After reviewing the literature on how and in what areas RLP regarding edible insects have been implemented, several issues become clear. Firstly, all studies see the value of eating insects. Secondly, the conservation of biodiversity and nature or habitats is vital, whether insects are farmed or not. Thirdly, insects are economically valuable and can help sustain an individual, a community, or even a country. Establishing not only a domestic, but also an international market can help raise standards of living in the Global South. However, to do so, more focus must – and inevitably will be – put on food safety, whether by formal or informal means. It is recommended by the majority of scholars to farm insects in order to ensure food safety, despite the issues that accompany farming and an intensified production. Opinions about how sustainable and efficient production should be carried out vary immensely, but scholars seem to almost exclusively agree on wild-harvesting as being environmentally unsustainable, with semi-wild harvesting only being slightly better. This leaves no clear answer as to what the optimal choice may be and any solutions will inevitably be contextual in nature. It is therefore still uncertain whether more RLP, more focus on food safety, and intensified production will increase or decrease consumer acceptance and consumption of insects.

On the one hand, RLP seem to be beneficial when they are targeted towards the right area (species, industry, etc.), but can cause great harm when too strict, too vague, or when financial incentives 'redirect' them. Thailand is a good example of how an edible insect industry can expand successfully, despite – or even due to – a lack of RLP. The Thai insect farming sector, for instance, would most likely not have been as great of a success if they had had to establish themselves initially within a formal economy. It is hard to conclusively say whether this has increased consumption as well, or if unrelated incidences, such as the internal migration in Thailand, have had a greater positive impact on the consumption and acceptance of edible insects as food. However, the beneficial outcomes of their informal economy and a lack of RLP could not have been known in advance. Therefore, establishing RLP – or standards – can prove very difficult before knowing how, and in which direction, each country will develop. However, due to the edible insect industry having had a positive impact on income generations and livelihoods in Thailand, along with several African countries like Zambia and Kenya, future policies should acknowledge the benefits of small- and medium-scale farming. As the edible insect industry becomes increasingly lucrative, and the desire for larger scales of production and farms increases, this might prove a significant obstacle for regulators, legislators, and policy makers, not just nationally, but also internationally in institutions like EFSA.

3.2 The Double-Edged Sword of Formalization

Both farmers and collectors can benefit greatly from an informal economy and lack of RLP, because they are not bound by specific ways of farming or collecting – and can avoid costly regulations and standards. A lack of formality and RLP can also act as a double-edged sword: when the financial incentive rises and there are no repercussions, the standard of environmental stewardship may fall. The level of inexperienced or indifferent newcomers may increase and even otherwise sustainable collectors can be tempted to increase the harvest in an environmentally degrading way. This may subsequently take its toll on the insect population, their environment, and ultimately the very people who overexploited the insects in the first place. Mexico, as mentioned earlier, provides an example of how several species have become endangered due to overharvesting (Ramos-Elorduy 2006).

The balance of enough, but not too many RLP, will therefore be one of the biggest challenges, especially with regards to wild or semi-wild harvesting. Insect foods and products must be available in sufficient quantities in order to be affordable to the local population, have a positive impact on malnutrition, and hopefully, with time, the environment by being a more sustainable food source. More research is required before such a production system can establish the best and most sustainable way of wild-harvesting in each specific country and context. It must also be established when traditional regulations are superior to formal, governmental regulations, and vice versa. This issue is critical and needs urgent addressing in each country and community where insects are wild-harvested. A lack of governmental care and arbitrary RLP, whether traditional or formal, can otherwise have a detrimental and even irreversible impact on ecosystems. As mentioned by Halloran et al. (2015), impact assessments of what effects an increase in insect consumption – and demand – has on the ecosystem are critically needed as well.

3.3 The Effects on Consumption and Final Remarks

Besides favoring wild insects over farmed insects in terms of consumption, there were only vague hints in the literature about whether consumption has been or will be affected by RLP. This is due in part to a current lack of literature in this area of research. One of the problems most closely linked to consumption is whether farmed insects can be produced in such a way that their quality, regarding size and taste, are equal to their wild-harvested counterparts. If this cannot be done, consumption might decrease, regardless of whether or not more formal RLP are implemented.

This area of research is incredibly multifaceted and interconnected with a wide array of other issues. The sheer number of topics that are yet to be understood and explored further complicates the process of determining which factors and variables play a role in each specific community, province, country, or region. It is also vital to remember the vast differences between – and indeed within – countries; culturally, economically, geographically, politically, etc. Indeed, the effects and solutions will also depend on the insect species, the supply chain, and how developed the market is. There are likewise many aspects that we have not been able to cover, or only briefly touched upon, that are all a part of the full equation.

Legislators, regulators, and policy-makers must be made aware of the potential and growth of the edible insect sector for future RLP development to be possible. Besides consumption, funding must be channeled into other key research areas such as food safety issues, environmental sustainability, best management practices, and international trade. Accordingly, much more research is needed in these areas if edible insects are to become a significant food source for the world. Hence, with current knowledge, it is impossible to bring any conclusive evidence of how consumption in the Global South has been affected by RLP. The issue is therefore still largely unresolved.

References

Akpalu W et al (2009) Can the restrictive harvest period policy conserve mopane worms in southern Africa? A bioeconomic modelling approach. Environ Dev Econ 14(05):587–600

APPA (2011) Import and Safety regulations. http://www.appa.com.au/import-and-safety-regulations. Accessed 20 July 2016

Balinga MP et al (2004) Contribution of forest insects to food security. The example of caterpillars in Central Africa. Rome, FAO

Costa-Neto EM (2015) Anthropo-entomophagy in Latin America: an overview of the importance of edible insects to local communities. J Insect Food Feed 1(1):17–23

Durst P, Hanboonsong Y (2015) Small-scale production of edible insects for enhanced food security and rural livelihoods: experience from Thailand and Lao People's Democratic Republic. J Insect Food Feed 1(1):25–31

EFSA Scientific Committee (2015) Risk profile related to production and consumption of insects as food and feed. EFSA J 13(10):1–60

Evans J et al (2015) "Entomophagy": an evolving terminology in need of review. J Insect Food Feed 1(4):293–305

FAO Département des Forêts (2004) Contribution des insects de la forêt à la sécurité alimentaire: l'exemple des chenilles d'Afrique Centrale. Programme des Produits Forestiers non Ligneux. FAO, Rome, p 112

Gahukar RT (2011) Entomophagy and human food security. Int J Trop Insect Sci 31(03):129–144

Gjerris M et al (2016) Ethical aspects of insect production for food and feed. J Insect Food Feed 1(1):1–10

Glover D, Sexton A (2015) Edible insects and the future of food: a foresight scenario exercise on entomophagy and global food security. Evidence report No 149. Policy Anticipation, Response and Evaluation. King's College, London. Institute of Development Studies, p 1–66

Gorham JR (1979) The significance for human health of insects in food. Annu Rev Entomol 24:209–224

Grabowski et al (2016) Practical key to identify entire edible insects sold as foodstuff or feedstuff in central Europe. J Food Safety Food Quality 67(1):1–28

Halloran A et al (2015) Regulating edible insects: the challenge of addressing food security, nature conservation, and the erosion of traditional food culture. Food Security 7(3):739–746

Halloran A et al (2017) The development of the edible cricket industry in Thailand. J Insect Food Feed 1(1):1–10

Halloran A, Magid J (2013) Planning the unplanned: incorporating agriculture as an urban land use into the Dar es Salaam master plan and beyond. Environ Urban 25(2):541–558

Hanboonsong Y et al (2013) Six-legged livestock: edible insect farming, collecting and marketing in Thailand. Food and Agriculture Organization of the United Nations, Bangkok, p 1–69

Kelemu S et al (2015) African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. J Insect Food Feed 1(1):1–17

Laurenza EC, Carreño I (2015) Edible insects and insect-based products in the EU: safety assessments, legal loopholes and business opportunities. Eur J Risk Regul 2:288–292

Lähteenmäki-Uutela A, Grmelová N (2016) European law on insects in food and feed. Eur Food Feed Law Rev 11(1):2–8

MacEvilly C (2000) Bugs in the system. Nutr Bull 25:267–268

Mbata KJ et al (2002) Traditional regulation of edible caterpillar exploitation in the Kopa area of Mpika district in northern Zambia. J Insect Conserv 6(2):115–130

Meyer-Rochow VB et al (2008) More feared than revered: insects and their impact on human societies (with some specific data on the importance of entomophagy in a Laotian setting). Entomologie Heute 20(2008):3–25

Niassy S et al (2016) African indigenous knowledge on edible insects to guide research and policy. J Insect Food Feed 2(3):161–170

Paoletti MG (ed) (2005) Ecological Implications of Minilivestock. Potential of Insects, Rodents, Frogs and Snails. Enfield, New Hampshire

Pascucci S, De-Magistris T (2013) Information bias condemning radical food innovators? The case of insect-based products in the Netherlands. International Food and Agribusiness. Manag Rev 16(3):1–16

Ramaswamy SB (2015) Setting the table for a hotter, flatter, more crowded earth: insects on the menu? J Insect Food Feed 1(3):171–178

Ramos-Elorduy J (2006) Threatened edible insects in Hidalgo, Mexico and some measures to preserve them. J Ethnobiol Ethnomed 2(1):51

Rumpold B, Schlüter O (2014) Nutrient composition of insects and their potential application in food and feed in Europe. Food Chain 4(2):129–139

Schabel HG (2010) Management of forest insects for food. Forest insects as food: a global review. In: Durst PB, Johnson DV, Leslie RN, Shono K (eds) Forest insects as food: humans bite back. Proceedings of a workshop on Asia-Pacific resources and their potential for development, Bangkok, Thailand, p 50–59

Syampungani S et al (2009) The Miombo woodlands at the cross roads: potential threats, sustainable livelihoods, policy gaps and challenges. Nat Res Forum 33(2):150–159

van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58(1):563–583

Yen AL (2009) Entomophagy and insect conservation: some thoughts for digestion. J Insect Conserv 13(6):667–670

Yen AL (2015a) Insects as food and feed in the Asia Pacific region: current perspectives and future directions. J Insect Food Feed 1(1):33–55

Yen AL (2015b) Conservation of Lepidoptera used as human food and medicine. Curr Opin Insect Sci 12:102–108

Yhoung-Aree J, Viwatpanich K (2005) Edible insects in the Laos PDR, Myanmar, Thailand, and Vietnam. In: Paoletti MG (ed) Ecological implications of Minilivestock. Science Publishers, Enfield, p 415–444

Legislation for the Use of Insects as Food and Feed in the South African Context

Saliou Niassy, Sunday Ekesi, Sheryl L. Hendriks, and Anjanette Haller-Barker

Abstract Nearly 50 different species of insects are reportedly consumed in South Africa, making it one of the most significant examples of entomophagy in Africa. While both small and medium enterprises are mushrooming in the country, legislative issues concerning the use of insects as food and feed are often overlooked. This chapter revisits the entire value chain of insects as food and feed and scrutinises the various entry points from a regulatory angle in the light of South African food laws. In South Africa, the regulation of food laws is overseen, for the most part, by four government departments. The Department of Agriculture, Forestry and Fisheries (DAFF), the Department of Health (DoH), and the Department of Trade and Industry (DTI). The Department of Environmental Affairs (DEA) is also involved for issues such as domestication and transportation of insects and for the promotion of good practices. The government ministries operate under common national acts, although not directly referring specifically to insects. We conclude that the policy environment in South Africa is conducive to the promotion of edible insects. However, the country lacks a national policy framework, preferring to rely on international frameworks (FAO, WHO). The present study calls for a concerted effort among the various stakeholders to deliberate this important question in South Africa.

S. Niassy (✉)
International Centre of Insect Physiology and Ecology (icipe), Nairobi, Kenya

Postgraduate School of Agriculture and Rural Development, University of Pretoria, Hatfield, Pretoria, Gauteng, South Africa
e-mail: sniassy@icipe.org

S. Ekesi
International Centre of Insect Physiology and Ecology (icipe), Nairobi, Kenya

S. L. Hendriks · A. Haller-Barker
Institute for Food, Nutrition and Well-being, University of Pretoria, Hatfield, Pretoria, Gauteng, South Africa

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_29

1 Introduction

There are more than 300 edible insects consumed in Southern Africa. In South Africa alone, nearly 50 different species of edible insects are consumed (Kelemu et al. 2015; Shackleton et al. 2002; Teffo 2006). The most known edible species in South Africa are the mopane worm *Imbrasia belina* Linnaeus, edible termites *Macrotermes* sp. and the edible stink bug *Encosternum delegorguei* Spinola.

The rich diversity and abundance of edible insects in South Africa coincides with the high demand in insect proteins, mainly motivated by food consciousness and awareness campaigns. The presence of motivated private companies that are eager to pursue any technology available in the dietary sector, particularly in food design, the feed industry and pharmaceutical businesses is an important factor to consider. Insect consumption can often be spotted in urban areas such as the Pretoria CBD and in some restaurants in Johannesburg (Rosebank Sunday market) where they are served along conventional foods. Recently, food business initiatives, such as "Pestaurant" have been organized in South Africa under the leadership of the company, Rentokil, and this seems to be highly appreciated by the participants. However, very few attempts have been made to bring these products to the shelves as whole products or as supplements, or to integrate them in high standard restaurants menus. The main explanation for this is that most edible insects are seasonal, which constrains the continuous supply thereof for industrial purposes, because large quantities must be supplied through a constant and similar protocol (FAO 2013).

On the other hand, there are some emerging companies such as Agriprotein, based in Cape Town. This company focuses mainly on the Black Soldier fly (BSF), and produces maggots to feed monogastric animals such as chicken, fish and pigs (Magmeal). It also produces an oil from the defatting process of the BSF maggot, which is rich in lauric acid, and is an immune boosting compound for cosmetic use (Magoil). The residue of the bioconversion by the Black Soldier fly maggot is commercialized as organic fertilizer (Magsoil). Agriprotein is a successful company aiming at expanding outside the continent with 50 facilities by 2020. However, the debate of using insects as food and feed in the country has not yet been posed.

The use of insects as food and feed could also be a solution to rampant unemployment as new opportunities through entrepreneurship and job creation (Van Huis 2013). Insect proteins are potentially cheaper than, and as valuable as, imported soybeans and fish meals and they can potentially be more cheaply mass produced (Okedi 1992; Farina et al. 1991; Oyegoke et al. 2006, 2013). In the feed business of many African countries including South Africa, imported ingredients, mainly from fishmeal and soy, account for up to 50% of the feed product. In the poultry sector, for instance, feed accounts for up to 80% of the total cost of chicken production. Feed companies are enthusiastically looking for protein replacements and insects have been proposed as a solution. Such substitutes, if locally produced, could significantly lower the cost of feed, create new jobs for the youth and introduce new options into the food and feed enterprises. Edible insects also represent a solution to nascent concerns related to environmental sustainability.

But why should we regulate the use of insects as food and feed in South Africa? – Despite the promising future of edible insects in South Africa, a number of challenges still hinder the commercialisation of edible insects and their products. Firstly, most edible insects are harvested from the wild, yet technologies to mass produce a wide variety of insects are available and need to be upscaled to ensure a continuous supply and to prevent the depletion of species (Niassy et al. 2016). Another component that precludes the expansion and entrepreneurship in this field is the lack of a legal framework (Halloran 2015; Halloran et al. 2015) which limits the potential of edible insects and kills any entrepreneurial spirit that could take these valuable products to the next level (CAC 2010). Considering the high demand in nutrient-rich products among South Africans and the robustness of the food systems and food chains in South Africa (including Woolworths, Pick n Pay, Checkers, ShopRite, Spar, etc..), it is of paramount importance to analyse the various components of the use of insects as food and feed in the light of South African food laws. Since entomophagy is practiced in the region, the South African model could easily be adopted in neighbouring countries. Therefore, the objective of this paper is to identify regulatory entry points for the use of insects as food and analyse South African regulatory set up to guide both regulatory entities, entrepreneurs and consumers.

2 The Chain of Edible Insects Used as Food and Feed and the Diversity of Edible Insects in South Africa

This section will provide an overview of the various elements in the use of insects as food and feed, the various actors and the outcomes that could be expected. We also provide basic information on the diversity and abundance of insects in South Africa and neighbouring countries in the SADC. Since most elements will be covered in the book, we will emphasize more on the legislation and regulation component which is cross-cutting. The next section reviews the set-up of South African food laws in respect to the use of insects as food and feed.

2.1 Edible Insects Chain

Generally, the use of insects for human consumption recognises the following issues or points to be analysed from a policy and legislative angle: (i) inventory, cultural and socioeconomic considerations and market analysis; (ii) mass rearing and harvesting technology; (iii) technological upscaling; (iv) nutritional composition and analysis; (v) disease risk and food safety; (vi) processing, storage and packaging; and (vii) organic waste conversion and regulatory issues, which are cross-cutting as these connect the uses to the expected outcomes (Kelemu et al. 2015). The components and the questions are illustrated in Fig. 1. Each of these

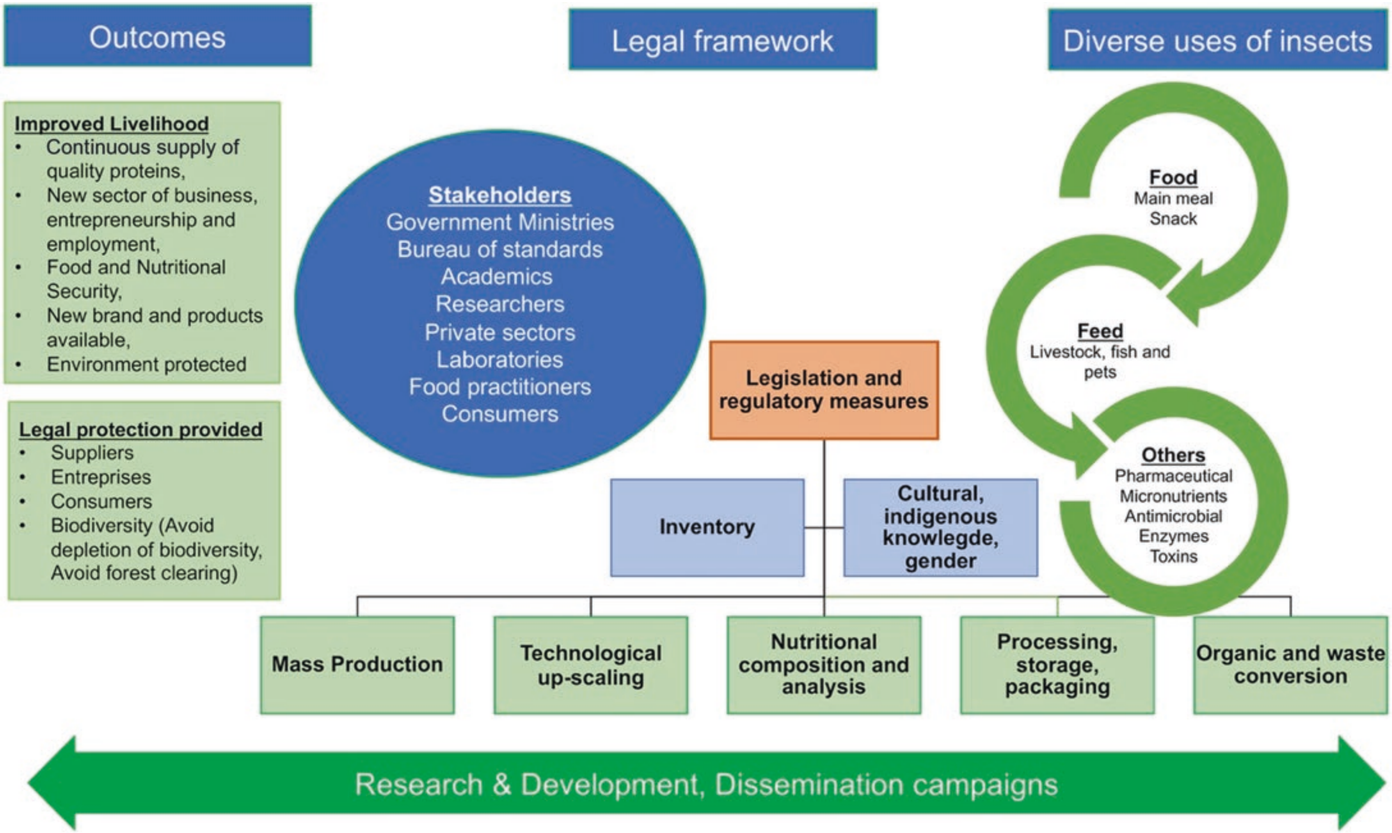


Fig. 1 Pathway for the development of a legal framework for the use of edible insects

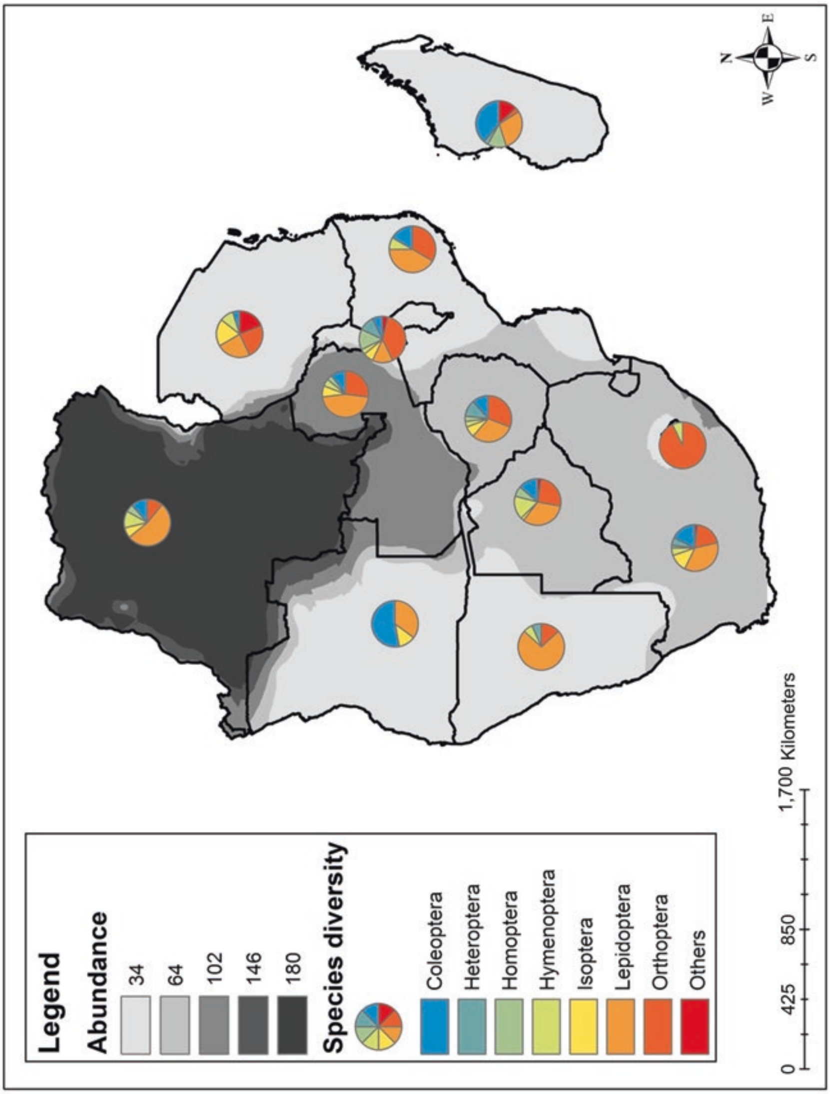


Fig. 2 Diversity and abundance of main groups of edible insects in southern Africa

Table 1 List of edible insects reported edible in South Africa and neighbouring countries in the SADC region

	Countries															
Species	DRC	Zam	SA	Zbw	Bot	Tan	Mlw	Ang	Mad	Moz	Nam	Les	Swz	Com	Mau	Sey
Nomadacris septemfasciata		x	x	x	x	x	x			x						
Cirina forda	x	x	x		x					x	x					
Carebara vidua	x	x	x	x	x		x									
Carebara lignata		x	x	x	x					x	x					
Urota sinope	x		x	x	x					x	x					
Phymateus viridipes brunneri		x	x	x	x					x	x					
Ruspolia differens	x	x	x	x		x	x									
Imbrasia belina	x	x	x	x	x		x									
Striphnopteryx edulis		x	x	x	x					x	x					
Schistocerca gregaria		x	x		x	x						x				
Macrotermes sp.	x	x		x		x	x									
Acanthacris ruficornis	x	x	x	x			x									
Apis mellifera	x	x			x	x						x				
Bunaea alcinoë	x	x	x	x		x										
Imbrasia ertli		x	x	x	x			x								
Locustana pardalina		x	x	x	x		x									
Bunaea caffraria	x	x	x	x		x										
Gynanisa maja		x	x		x		x				x					
Heniocha dyops			x	x	x					x	x					
Heniocha marnois			x	x	x					x	x					
Anacridium burri			x	x	x					x	x					
Brachytrupes membranaceus	x	x		x		x										
Anaphe panda	x	x		x		x										
Cirina butyrospermi	x	x	x	x												
Imbrasia epimethea	x	x	x	x												
Oryctes boas	x		x		x						x					
Ceroplesis burgeoni		x	x	x	x											
Agrius convolvuli		x	x	x	x											
Acrida acuminata			x		x		x					x				

X **reported consumed,** *DRC* **Democratic Republic of Congo,** *Zam* **Zambia,** *SA* **South Africa,** *Zbw* **Zimbabwe,** *Bot* **Botswana,** *Tan* **Tanzania,** *Mlw* **Malawi,** *Ang* **Angola,** *Mad* **Madagascar,** *Moz* **Mozambique,** *Nam* **Namibia,** *Les* **Lesotho,** *Swz* **Swaziland,** *Com* **Comoros,** *Mau* **Mauritius,** *Sey* **Seychelles**

components contain a set of requirements and questions that need to be legally addressed to protect consumers, but also the potential entrepreneurs and suppliers, whether operating on a small or industrial scale and opening new areas of business (Fig. 2).

2.2 *Diversity of Edible Insects in South Africa and the Region*

The knowledge of the diversity of insects consumed is essential for any country that aims to address the regulatory aspects of the use of insects as food and feed (Kelemu et al. 2015). The list of edible insects reported consumed in South Africa and the region are presented in Table 1. In the context of clear regulatory framework, these species need to be catalogued and characterised. The establishment of such a catalogue should be based on taxonomic knowledge but also on socioeconomic and cultural knowledge.

3 Review of Legislation, Regulations and Standards in South Africa

In South Africa, the regulation of food laws is for the most part overseen by four government departments: the Department of Agriculture, Forestry and Fisheries, the Department of Health, the Department of Trade and Industry and the Deartment of Environmental Affairs. Each department is responsible for the implementation and enforcement of many policies, legislation, and regulations pertaining to, *inter alia*, food production, harvesting, storage, transportation, processing and sale. These government departments function at national, provincial and local levels. Each level has legislative powers of its own. The regulation of food laws over various government departments, and on three levels of government, results in a fragmented system of laws, with no cohesive framework legislation tying these together. This may result in gaps in legislation, and problems with enforcement.

3.1 The Department of Agriculture, Forestry and Fisheries (DAFF)

The Department of Agriculture, Forestry and Fisheries oversees a large number of Acts, regulations and policies related to agricultural production, although none of these pertains specifically to insects. However, it is suggested that the regulation of insects for consumption could be achieved in terms of the following:

(a) **The Agricultural Products Standards Act (Act 119 of 1990)**: This provides control over the sale, export and import of certain agricultural and other related products. The various aspects of quality control set out in the Act are achieved through the publication of regulations under the Act, detailing the standards for the production, control and sale of specific foodstuffs. These could include insects or insect products.

(b) **The Marketing of Agricultural Products Act (Act 47 of 1996)**: This provides for "the establishment and enforcement of regulatory measures to intervene in the marketing of agricultural products" (set out in the preamble to the Act), amongst other things. Whilst these do not specifically include insect products, due to impurity, connotation or quarantine considerations, Van Huis (2015) noted that when the word 'animal' is used in legislation, this would refer to insects as well, although the content of the legislation may not be appropriate in the context of insects.

(c) **The Fertilisers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act 36 of 1947)**: regulates various aspects of the animal feed industry. Whilst it makes no specific reference to insect additives, it is suggested that this Act would be the relevant one for the regulation of insect additives in stock feed.

The South African Policy on Animal Feeds (GN 511 in GG 31005 of 30 April 2008) emphasises "food safety through feed safety" and the application of global quality standards in the animal feed industry. Insects are increasingly used in feed production (for example termites and black soldier fly maggots), due to their high nutritive value, but in most instances, no safety analysis has been done. However, some insects are not accepted as being suitable for use in animal feeds (because they are poisonous or undesirable for ethical or cultural reasons). In the future, it will be a priority to test insect-derived products, to analyse their safety for use in feeds, and also to label these on the final product.

3.2 The Department of Health (DoH)

The Department of Health (DoH) is responsible for the safety of food products to the consumer. In particular, this department oversees the regulation and enforcement of the Foodstuffs, Cosmetics and Disinfectants Act (Act 54 of 1972). This is an important Act, under which many regulations have been promulgated, most of which relate to health and safety issues. These include various additives, labelling, application of the HACCP system, hygiene requirements for certain industries, perishable foodstuffs, and tolerances for fungus-produced toxins, to name but a few. Again, the Act has no regulations relating specifically to insects, but the health and safety aspects of using insect products would fall under this Act.

On a local level, the sale of food must comply with municipal by-laws on the handling, vending and sale of food. These by-laws may be couched in general terms, mostly from a health perspective, and therefore they are regulated and enforced by the Department of Health. They generally allow for health officers to inspect and confiscate foodstuffs. Whilst insects are not specified in any of these by-laws, neither are other foodstuffs specifically mentioned and therefore the by-laws are broad enough to include insects. By-laws generally mandate a permit for the sale of food, and they often refer to codes of practice for the handling of certain foodstuffs.

3.3 The Department of Trade and Industry (DTI)

The Department of Trade and Industry (DTI) oversees a number of important Acts related to food control. These include the Standards Act (Act 8 of 2008), the Consumer Protection Act (Act 68 of 2008), the National Regulator for Compulsory

Specifications Act (Act 5 of 2008), and various Acts relating to standards and metrology. The Standards Act, in the preamble to the Act, sets out that its purpose is to provide for "the continuation of the SABS as the peak national standardisation institution in South Africa responsible for the development, maintenance and promotion of South African National Standards; ensure provision of an internationally recognised standardisation system; and promote South African National Standards as a means to facilitate international trade".

The South African Bureau of Standards (SABS) "provides standards and conformity assessment services to industry" (SANS 1–1: 2012 Edition 3). It is a member of various international and regional bodies, including the International Organisation for Standardisation (ISO) and the Committee for Standards Development within the Southern African Development Community (SADCSTAN), and participates in the Codex Alimentarius Commission (CAC).

The National Regulator for Compulsory Specifications (NRCS) was established in terms of the National Regulator for Compulsory Specifications Act. It was originally part of the Regulatory Division of the SABS, but now stands as an independent organisation. It states its mandate as being to "promote public health and safety, environmental protection and ensure fair trade through the development of technical regulations and compulsory specifications as well as through market surveillance to ensure compliance with the requirements of the compulsory specifications and technical regulations" (www.nrcs.co.za). The SABS is now a certification body that is accredited by SANS.

Although there are certain South African standards related to insect products as a component of animal feeds, there are no standards relating to insect and insect products for human consumption. In general, where national food laws are lacking in respect of a particular commodity, reference will be made to the Codex Alimentarius as a guide. However, the Codex has no provisions relating specifically to insects. It has been suggested that the EU may include insect products in their food regulations, through the incorporation of the new EU Novel Food Regulation (Regulation EC No. 258/1997), but it seems this has not yet been done (Van Huis 2015). For a discussion of this, see Belluco et al. (2013).

The Consumer Protection Act (CPA), also overseen by the Department of Trade and Industry, regulates all consumer products and services, and its objectives include the establishment of norms and standards related to consumer protection in South Africa, and improved standards of consumer information (these objectives are set out in the preamble to the Act). The CPA, therefore, encompasses all products and services along the entire food production chain. The Act set out the consumer's right to disclosure and trade descriptions, which includes product labelling, and in particular the labelling of GMO products (section 24 of the Act). Importantly, the CPA sets out the consumer's right to safe, high-quality goods, which includes compliance with any applicable standards set under the Standards Act, or any other public regulation (section 55 of the Act). One of the far-reaching provisions of the CPA is the inclusion, in section 61, of strict liability for damage caused by goods. This means that if goods cause harm, there is no requirement to prove fault on the part of the supplier – they may be found liable for the harm by the mere fact that they supplied the goods that caused the harm. Potentially, then, any party along the food supply chain may be liable. This may be of concern to producers or suppliers of insect products that have not been analysed for safety and/or quality. It also means that insect products must comply with certain standards in order to be deemed safe for the consumer market, and they must be adequately labelled. Failure to supply safe, quality goods may result in notices, penalties or administrative fines under the CPA.

Although the three government departments discussed above oversee much of the regulation of food laws, another department with a role to play in the production of insects for commercial consumption would be the Department of Environmental Affairs.

3.4 The Department of Environmental Affairs (DEA)

The Department of Environmental Affairs (DEA) oversees the functioning of the National Environmental Management: Biodiversity Act (Act 10 of 2004 - NEMBA). This Act incorporates many of the provisions of the international Convention on Biological Diversity (CBD), to which South Africa is a signatory. Under both the CBD and NEMBA, the conservation of insect species would have to be taken into account. Harvesting of insects for personal use, or for sale in informal markets, has the potential to impact the population numbers of insect species, and would be a threat to biological diversity and ecosystem stability. Commercial production of insects would likewise have to take into account any threats to conservation, depending on the harvesting and production techniques employed (also see Halloran et al. 2015: 739–746). A further concern would be the utilisation of insects considered to be indigenous biological resources. This would involve the application of the NEMBA provisions relating to bioprospecting, as well as the Regulations on Bioprospecting, Access and Benefit Sharing, promulgated under NEMBA.

It should be noted that the above is an overview of some of the major legal instruments which are currently used for food and feed control in South Africa. Whilst this represents the laws behind commercial food production and supply, South Africa (as with the rest of Africa) has a very large informal food market. Thus, whilst insects and insect products have not featured on a commercial scale as yet, they have always been a part of the informal food market. As such, the municipal by-laws referred to above become an important tool for the regulation of insect consumption in the informal sector, mandating that certain standards, licensing and quality control factors are met. However, problems with the capacity of officials may mean that there is insufficient enforcement of by-laws, and the food trade in insects remains largely unregulated.

4 Discussion

The diversity of insects consumed in South Africa is rich and insect-based products are being considered in food and feed industry in South Africa. As interest grows and companies emerge, the business of edible insects seems to be lucrative with high potential. However, the formal integration of insects as food or feed has to be dealt with in a holistic manner considering the multi-dimensional use of insects as food and feed. In this context of high demand, the “noisy silence” of stakeholders and legislation entities on this topic is alarming. In addition to the seasonal nature of some insects, there are other reasons that could explain this inaction. Entomophagy is an ancient practice found in remote areas where concerns are less prominent and law enforcement systems too weak to oversee activities. Another explanation could be the lack of a regulatory model that takes into account the entire commodity value chain of edible insects in order to guide stakeholders on the adequate decisions expected from them. Finally, the handling of edible insects in Africa raises many health-related questions, contributing to a degree of disgust. It is assumed that in an environment where insect consumption is accepted by most communities of the country, and forms part of the cultural heritage, the regulatory framework should not be as complicated as in countries where insects are promoted as a novel food.

Elsewhere, some countries have already engaged the process of developing their own policies (Halloran 2015). While the Laos DPR submitted to the FAO within the Codex Alimentarius (CAC 2010) has been long delayed by international communities, the reformed EU Novel Food Regulation No. 2015/2283 is a pertinent expression of the novelty of this question. Insects have been officially introduced into the European Union (EU) market as foodstuffs to ensure food safety (Grabowski et al. 2016).

Halloran et al. (2015) presented comparative case studies of regulatory mechanisms that led to the integration of insects in food laws in Thailand, Switzerland, Kenya and Canada. In Thailand, the government is involved in promoting insect farming, while in Switzerland the citizens advocated for it. The approval of Swiss Parliament of a law allowing the commercialisation of insects as food was a turning point in many countries particularly in the EU, where the novel foods regulation (EU) 2015/2283 prevails. Precautions are taken to clearly identify the categories and species of insects allowed to be used as food or to comply with laws relating to biodiversity preservation. Each of these scenarios is unique and could be a learning process for South Africa. The International Centre of Insect Physiology and Icology-*icipe* has been pioneering the integration of insects in the feed system in Kenya and Uganda under the INSFEED project. The aftermath of this project is that, introducing insect based feeds requires dried insects as a raw material and the National Livestock Feed Committees of both countries released standard for on the use of insect-based feed in 2017. We can therefore expect several brands of insect-based products to emerge in a near future in the two countries.

Going through the regulatory set up in South Africa, we found several laws and by laws that could accompany the regulation of insects, although most of them do not specify the use of insects. However, consumer protection, hygiene and safety, production, development of standards and compliance with biodiversity laws were at the core of the scope of the Acts. Hence in the advent of more dynamic enterprises and new products, it is crucial to depart from the current inaction and pose the debate in relevant instances by being more specific on the use of insects as food and feed.

Insects are relegated to the status of contaminants or impurities, therefore unfit for human consumption. The development of standards for insect based products for human consumption is crucial in South Africa. The Consumer Protection Act (CPA), suggests the establishment of norms and standards related to consumer protection in South Africa. However, as explained above and as point out by Halloran et al. (2015), most countries depend on the WHO and FAO to provide them with information that is often adopted as national dietary guidelines or used as the basis for their own standards. This situation implies that the use of insects as food and feed and related questions are being taken for granted. The authors suggest the establishment of a Council of Science to discuss new policies such as those pertaining to the consumption of insects. The governance of such council may be overseen by a Steering Committee of Stakeholders that holds technical committee meetings e.g. experts from different fields: Environment; Ministry of Agriculture; traders; food/feed companies; manufacturers, and affected persons. The council could hold regular meetings (requiring a quorum of at least a representative of each institution: DAFF, DoH, DTI and DEA, Chemists, Academics, National Agricultural Agencies and Resources) to provide input on this matter. There is also a need to consider research laboratories that have the facilities and the competence to provide data and, where more than one laboratory is used, it should be ensured that results are similar across the various laboratories, with any level of uncertainty being within the desirable range.

Insects are part of wildlife and play an important role in the environment. The Department of Environmental Affairs, through SANParks and SANBI, should be involved in the policy dialogue and the development of good practices pertaining to the sustainable use of edible insects and the preservation of endangered species. For instance, Twine et al. (2003) reported that savannah resources, including edible insects, can contribute to household well-being up to R3959 mean annual direct use. There several reports on the depletion of Mopane worms in Southern Africa due to erratic rainfall but also habitat loss. Akpalu et al. (2009) studied the restrictive harvesting period policy advocated by community leaders for the sustainable use of the Mopane worm in South Africa; this would permit sustainable harvesting. Moreover, there are issues of domestication and transportation for moving animals, similarly to KWS in Kenya (Halloran et al. 2015). The Department of Agriculture, Forestry and Fisheries and the Department of Environmental Affairs should, therefore, work together with relevant agencies to develop a Good Practices Index for the farming or wild harvesting of some of the most popular edible insects, as suggested by Thomas (2013) in Namibia.

5 Conclusion

Being the leading economy in the region, South Africa has a well-developed food sector with the comprehensive integration of agricultural commodity value chains. The country could serve as a leading example in the promotion of entomophagy and insect-based products in the region and the continent as a whole. In order to achieve this, there is a need to identify the stakeholders and their roles in regulating the use of insects as food and feed. However, while small and medium enterprises in the business of insects are expected to emerge, there is a need to formulate the existing policies to take into account the use of insects.

It can be concluded that the legal instruments to regulate the use of insects as food and feed in South Africa do exist. However, there is a lack of specificity of the food laws in reference to insects. Entomophagy is widely practiced and accepted by most communities in South Africa. Taking examples from other countries, edible insects are not novel food in South Africa and insects are being traded in the country and across South Africa informally. Hence there is need to stimulate the regulatory debates. Although policy gaps are covered in international guidelines, the establishment of a council of stakeholder and actors is highly recommended. These actors should work together with food practitioners to deliberate on the use of insects in South Africa.

References

Akpalu W, Muchapondwa E, Zikhali P (2009) Can the restrictive harvest period policy conserve mopane worms in southern Africa? A bioeconomic modelling approach. Environ Dev Econ 14(5):587–600. https://doi.org/10.1017/S1355770X0900518X

Belluco S, Losasso C, Magioletti M, Ricci A (2013) Edible insects in a food safety and nutritional perspective: A critical review. Comprehensive Reviews in Food Science and Safety 12:296

CAC (Codex Alimentarius Commission) (2010) Development of regional standards for edible crickets and their products. FAO/WHO, Rome

FAO (Food and Agriculture Organisation) (2013) Edible insects: Future prospects for food and feed security. FAO, Rome

Farina L, Demey F et al (1991) Production of termites for poultry feeding in villages in Togo. Tropicultura 9(4):181–187

Grabowski NT, Grootaert P, Ahlfeld B, Klein G (2016) Practical key to identify entire edible insects sold as foodstuff or feedstuff in central Europe. J Food Safety Food Qual 67(1):4–11

Halloran A (2015) Discussion paper: Regulatory frameworks influencing insects as food and feed. FAO, Rome

Halloran A, Vantomme P, Hanboonsong Y, Ekesi S (2015) Regulating entomophagy: The challenge of addressing food security, conservation, and the erosion of traditional food culture. Food Security 7(3):739–746

Kelemu S, Niassy S, Torto B, Fiaboe K, Affognon H, Tonnang H, Maniania NK, Ekesi S (2015) African edible insects for food and feed: Inventory, diversity, commonalities and contribution to food security. J Insect Food Feed 1(2):103–119

Niassy S, Fiaboe KKM, Affognon HD, Akutse KS, Tanga MC, Ekesi S (2016) African indigenous knowledge on edible insects to guide research and policy. J Insect Food Feed 2(3):161–170

Okedi J (1992) Lake flies in Lake Victoria: Their biomass and potential for use in animal feeds. Insect Sci Appl 13(1):137–144

Oyegoke OO, Akintola AJ, Fasoranti JO (2006) Dietary potentials of the edible larvae of *Cirina forda* (Westwood) as a poultry feed. Afr J Biotechnol 5(19):1799–1802

Oyegoke OO, Ayandiran TA, Akintola AJ (2013) Cost effectiveness of replacing fish meal with *Cirina forda* (Westwood) larva in the diets of broilers, scihub.org

Shackleton SE, Shackleton CM et al (2002) Use patterns and value of savanna resources in three rural villages in South Africa. Econ Bot 56(2):130–146

Teffo LS (2006) Nutritional and medicinal value of the edible stinkbug, *Encosternum delegorguei* Spinola consumed in the Limpopo Province of South Africa and its host plant *Dodonaea viscosa* Jacq. var. *angustifolia*. PhD Thesis in Paraclinical Sciences, University of Pretoria, Pretoria

Thomas B (2013) Sustainable harvesting and trading of mopane worms (*Imbrasia belina*) in Northern Namibia: An experience from the Uukwaluudhi area. Int J Environ Studies 70(4):494–502

Twine WM, Netshiluvhi DT, Siphugu V (2003) Consumption and direct-use values of savanna bio-resources used by rural households in Mametja, a semi-arid area of Limpopo province. South Africa: Res Lett 99:467–473

Van Huis A (2013) Potential of insects as food and feed in assuring food security. Annu Rev Entomol 58:563–583

Van Huis A (2015) Edible insects contributing to food security? Agric Food Sec 4:20

Current Status of the Insect Producing Industry in Europe

Christophe Derrien and Andrea Boccuni

Abstract This chapter offers insights into insect production activities in Europe and provides an overview of the main EU legislative provisions applying to the production and consumption of insects and products thereof in Europe, both for food and feed applications. The last part elaborates on the main missions, activities and political messages of the International Platform of Insects for Food & Feed (IPIFF). The elements outlined throughout this chapter are mainly based on information collected through the IPIFF contacts: the content of this chapter does therefore not necessarily provide a complete representation of the current status of the sector. Whilst it mainly draws on objective information, this chapter also contains pieces which solely represent the views of the organisation.

1 The European Insect Production Sector for Food and Feed

1.1 European Insect Producers Profile

The European insect production sector is represented in its vast majority by small and medium-size enterprises. Most of these actors are start-up companies, whereas few of them are long-established businesses, who based on their experience in the production of insects, such as for biocontrol purposes or the production of feed for pet food or zoo animals, decided to diversify their production activities toward food production or feed production for farmed animals.

C. Derrien (✉)
The International Platform for Insects as Food and Feed (IPIFF) Secretary General, Brussels, Belgium

A. Boccuni
The International Platform for Insects as Food and Feed (IPIFF) Communication Advisor, Brussels, Belgium

A. Halloran et al. (eds.), *Edible Insects in Sustainable Food Systems*,
https://doi.org/10.1007/978-3-319-74011-9_30

1.2 Insect Species Currently Reared for Human Consumption and/or Animal Feed in Europe

Insects and insect-based products are consumed in different forms, the most used practice being to process them into food or feed ingredients (e.g. flour or powder) which are then incorporated in final products such as energy bars, burgers or compound feed. However, insects are also sold whole and/or in various processed forms.

Insects are produced and sold across Europe: most widespread species intended for human consumption include larvae from yellow mealworm (*Tenebrio molitor*), lesser mealworm (*Alphitobius diaperinus*) as well as house cricket (*Acheta domesticus*) and banded cricket (*Gryllodes sigillatus*).

Several insect farms established in Europe produce and sell insects (including as live animals) for pet food and/or for 'new pet food' (e.g. reptiles), circus and/or zoo animals markets: the main species produced are larvae from yellow mealworm and lesser mealworm as well as black soldier fly (*Hermetia illucens*), wax moth (*Galleria mellonella*), grasshoppers, silk moth (*Bombix mori*) and cricket species (including banded crickets, house cricket and field crickets – *Gryllus assimilis*).

Black soldier fly (*Hermetia illucens*), yellow mealworm (*Tenebrio Molitor*) and to a lower extent lesser mealworm (*Alphitobius diaperinus*) constitute the most relevant species that are sold as derived products for farmed animal feed: today, around 80% of EU insect producing companies breed or process Black soldier fly. Most commonly marketed products are derived fats and oils or animal proteins which are allowed for use across the European Union, in feed for pet food animals or in feed for aquaculture animals since 1st July 2017.

Finally, the house fly species (*Musca domestica*) is being produced by several European companies. Apart from the abovementioned species, several producers are engaged in research activities on the use of other insect species as animal feed.

1.3 Location of European Insect Producers

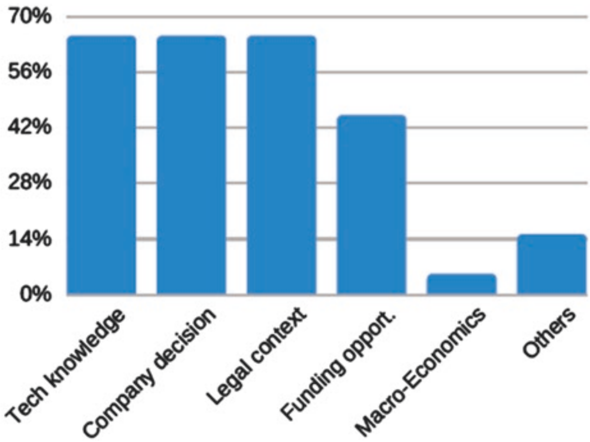
Based on the latest outreach, we know that European producers of insects for animal feed and/or human consumption (e.g. proteins and fats) are present in the vast majority of the 28 EU Member States: among these 28 countries, the Netherlands and France are overrepresented either in terms of number of producers and/or of volumes produced. This situation might be explained by the fact that these countries had a longer history of production of insects for of pet food or zoo animals 'niche markets'.

Insect producers farming live insects for pet food markets, circus & zoo animals markets have also been identified in the Czech Republic, Romania, Spain, Germany, United Kingdom and Belgium.

1.4 Current State of Development of the European Insect Production Sector

Most EU producers use exclusively indoor systems, which allows for proper insect growth and development. They also developed advanced production techniques, based on the automation of most processes and the optimization of insect rearing conditions and diet formula. These elements being a precondition for mass scale production of insects. Owing to the above developments, the European insect industry is today a world leader in terms of innovation and technological advancement.

The ability of EU producers to keep this leadership will, however, depend on whether the conditions of a favourable EU regulatory environment can be met in the next few years. Apart from the recent authorization granted for the use of insects proteins as feed for aquaculture animals, the capacity of many companies to plan their investments and to deploy their production activities at wider industrial scale will indeed depend on the concretisation of other EU legislative opportunities, both in the food and feed sectors: notably, the future possible authorisation of novel food applications covering insects or of insect proteins for use in pigs and poultry feed should constitute a major step forward.



"What are the main factors which may impact the growth of the European insect sector?" – Answers to the IPIFF survey "Overview of the insect production sector" (31 March 2017)

1.5 The 'Economic Weight' of the Sector and Future Growth

According to IPIFF' studies, today, the total EU production only represents a few thousand tonnes, whilst investment accounts for approximately 150 Million Euros. While the sector today generates about a few hundred jobs, we expect these figures to increase up to a few thousands by 2025. Indirect jobs may increase to one or two thousand by that time[1]: notably the sector should create new jobs at supplying level through the development of activities related to the provision of dedicated equipment or substrates destined to the production of insects. Insect producers should use specialized services, i.e. diet formulators, operators specialized in insect biology and genetic or insect breeding activities. Furthermore, research activities aiming at improving insect production conditions should also develop.

2 European Regulatory Context: Are Insects and Insect Products Authorised?

2.1 Insects for Human Consumption in Europe

The production and marketing of insects for human consumption within the EU is governed by the so-called EU 'novel food' legislation – i.e. Regulation No 2015/2283. According to this legislative text, insect products must receive a European authorisation, based on a safety evaluation conducted by the European Food Safety Authority with the view to be legally placed on the EU market. To this end, the insect producing company must submit a comprehensive application dossier, containing pieces of evidence demonstrating the safety of the product for human consumption. This legislation applies since 1st January 2018.

2.2 Insect Proteins in Farmed Animal Feed?

Two main restrictions currently hinder the use of insect proteins for feed production. The first one is a prohibition of using certain types of animal protein in feed, commonly referred to as the 'feed ban'. The feed ban was introduced as a reaction to the so-called BSE crisis (Bovine Spongiform Encephalopathy (BSE), known as mad cow disease), and is laid down in Regulation No 999/2001. This legislative text prohibits the use of animal derived protein in feed for farmed animals. As consequence of these rules, the possibilities for feeding insects to farmed animals are very limited. However, The European Commission recently adopted Regulation which amended Regulation 999/2001 to authorise the use of insect processed animal proteins (PAPs) in feed for aquaculture animals – i.e. Regulation 2017/893. The text was formally adopted by the European Commission on 24 May 2017. This authorisation is effective since 1st July 2017.

The second restriction concerns the possibilities to use certain materials as feed for insects. Insects kept in the EU for production of food, feed or other purposes are

[1] Information collected through IPIFF members – Survey '*overview of the insect production sector*' - 31 March 2017.

considered as ‘farmed animals’ in accordance with article 3.5 & 3.6 of Regulation (EC) N °1069/2009 on Animal By-products. This means that the possibilities for feeding insects with animal origin materials are very limited: only products and/or by-products of vegetal origin as well as few products and/or by-products of animal origin are authorised: i.e. fishmeal, blood products from non-ruminants, di and tri-calcium phosphate of animal origin, hydrolysed proteins from non-ruminants, hydrolysed proteins from hides and skins of ruminants, gelatine and collagen from non-ruminants, eggs and egg products, milk, milk-derived products and colostrum, honey and rendered fat. Conversely, insects cannot be fed with feed materials which are especially prohibited for use in animal feed: namely slurry or manure, catering waste & unprocessed former foodstuffs containing meat or fish.

Besides the abovementioned restrictions, the production of insect proteins must respond to stringent safety standards: notably, production and processing facilities based in the European Union must be approved by national competent authorities, whilst complying with microbiological standards – i.e. Enterobacteria, Clostridum, and Salmonella – specific hygiene conditions as well as defined processing methods.

2.3 The Aqua Feed Authorisation: Main Provisions of Regulation 2017/893

Regulation 2017/893 introduces a specific section for insects and insect products, i.e. Annex IV, section F of Regulation 999/2001, which allows insect-producers to make use of the same authorisation as the one benefiting to those producing and processing other non-ruminant animals for feeding aquaculture animals.

The authorisation is limited to seven insect species, namely to the followings: black soldier fly, house fly, yellow mealworm, lesser mealworm, house cricket, banded cricket and field cricket. Furthermore, the authorisation only applies to insects which have been fed with substrates that are eligible as feed materials for farmed animals (‘feed grade substrates’): these mainly include vegetal origin materials, but also a few products of animal origin, which are mentioned in Sect. 2.2 above. The same rules apply to insect PAPs that are imported from EU third countries (Fig. 1).

3 The International Platform on Insects as Food and Feed

3.1 IPIFF in a Nutshell

The International Platform for Insects as Food and Feed (IPIFF) is an EU non-profit organisation which represents the interests of the insect production sector towards EU policy makers, European stakeholders and citizens. It was funded in

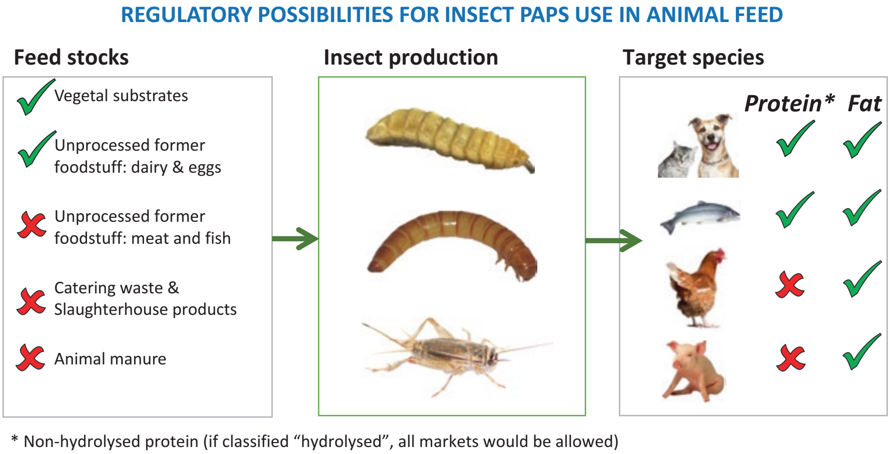


Fig. 1 EU legal opportunities for the use of insects Proteins of Animal Processed (PAPS) in animal feed (Reproduced from IPIFF Brochure)

2012, in the wake of an expert consultation meeting organized by FAO jointly with Wageningen University and gathering international (public & private) experts to discuss the potential benefits of using insects for food and feed. At that time, 5 insect producing companies decided to join forces to promote the interests of the insect production notably towards international instances. The IPIFF membership being composed in its vast majority by insect producing companies that are established in Europe, i.e. 37 out of 42 members today. IPIFF gradually narrowed down its scope to European geographic area: this shift being consistent with the fact that regulatory challenges insect producers must overcome main stem from the European legislation.

This move is also consistent with the recent creation of associations such as ASEAN Food and Feed Insects Association (AFFIA) or The North American Coalition for Insect Agriculture (NACIA), which represent the interest of insect producers, respectively in South East Asia and in Northern America;

Whilst the IPIFF association is governed by insect producers, its membership is opened to all interested operators within the insect value chain, from breeding up to the final selling point. Furthermore, IPIFF collaborates with recognized universities and research institutes as well as with several insect producers established outside Europe. Collaboration may range from the sharing of economic figures or statistics for the sector to the development of joint positions & actions towards the Food & Agriculture Organisation (FAO) of the United Nation or the setting of joint standards in the context of the Codex Alimentarius.

3.2 IPIFF Representation

Owing to its missions and current membership, IPIFF represents the interests of insect producers in Europe. In addition to that, IPIFF is the recognized organisation of the EU insect production sector by the EU institutions. Through its membership, most of which are European based companies, IPIFF is present in fourteen European countries

- France: nine members
- Switzerland: three members
- The Netherlands: five members
- Italy: four members
- Belgium: two members
- Germany: three members
- United of Kingdom: one member
- Spain: one member
- Denmark: one member
- Sweden: one member
- Poland: one member
- Ireland: two members
- Lithuania: one member
- Bulgaria: one member

The association comprises members in Israel (3 members) in the United States (one member), South Africa (one member) and in Malaysia (one member).

IPIFF members are either producing insects for animal feed or active in insect production for sale on the EU market.

Registered in the EU transparency register, IPIFF is a member of two EU consultative platforms established by the EU public authorities: The Advisory Group on the food chain and animal and plant health or the European Food Safety Authority Stakeholders' Forum.

3.3 IPIFF's Mission

IPIFFs mission is to promote the wider use of insects as an alternative or new source of nutrients for human consumption and animal feed. IPIFF does so by advocating for appropriate EU legislative frameworks to apply to insect production, through continuous dialogue with EU decision makers: namely the European Commission, EU Member States authorities, the European Parliament and the European Food Safety Authority. The association also supports its members in the effective implementation of EU food and feed safety legislations, such as through the promotion and/or development of shared standards. More generally, IPIFF aims to communicate on the benefits of eating insects and/or their use as animal feed towards the wider public.

4 IPIFF's Position on the Current European Regulatory Framework

4.1 EU Legislation on 'Novel Foods' and the Impact on the Insect Sector

Replacing the current EU Regulation (EC) 258/97, Regulation (EU) 2015/2283 on 'novel foods' clarifies the legal status of insects and their derived products – including 'whole insects and their preparations'– by specifying that these products fall within the scope of the new novel foods legislation: consequently, insect products which have not been consumed to a significant degree within the European Union before 15 May 1997 must be assessed and receive a European authorization with the view to be legally placed on the EU market as from 2018. The text applies since 1st January 2018.

IPIFF emphasizes the importance for EU authorities to establish workable rules and to provide guidance at implementation stage. These principles, along with appropriate transitional measures, are notably relevant to facilitate the uptake of this new legislation by insect producers.

4.2 EU Legislative Reforms for the Use of Insects for Feed

The IPIFF members are committed to take the necessary steps with view to ensure full implementation of the provisions contained in Regulation 2017/893 (the so-called aqua feed authorization) and in Regulation 2015/2283 on novel food. To this end, the IPIFF association is currently developing an EU guideline on good hygiene practices for insect production. This document, whose publication is expected by before the summer 2018, aims to describe the minimum general standards followed by insect operators through their production activities, whilst supporting them in the effective application of the general requirements stemming from EU food & feed safety legislations. Covering both food and feed production activities as well as all production steps, this document is expected to assist insect businesses in stepping up their production methods to minimum safety standards.

Pending the availability of validated analytical/detection methods, IPIFF pleads for a new 'relaxation' of the EU feed ban rules to authorise the use of insect PAPs in feed for other non-ruminant livestock animals – i.e. pigs & poultry species.

In our view, further investigations should also be engaged on options for extending the EU legislative possibilities to upgrade other valuable resources through insects. One priority subject of analysis could notably be to explore the conditions for the safe use of unsold products from supermarkets or discarded materials due to manufacturing or packaging defects – or 'former foodstuffs' – and of food losses originating from restaurants or catering establishments. To this end, IPIFF supports the mandating of the European Food Safety Authority to deliver fully documented conclusions on the potential risks associated with the use of such materials. Their authorization as feed for insects could be envisaged, in case demonstration is made that these do not entail safety risks nor adverse health effects on the targeted animals.

Several IPIFF members are already conducting internal research programmes or collaborating with prominent academics and research institutes (such as through participation EU funded research projects) to advance available research on the above subjects.

5 Conclusions

The European insect sector is an emerging industry which concentrates most research and innovation efforts that are invested into the sector worldwide. Legislative decisions taken by EU policy makers from 2015 onwards, as notably materialized by the revision of the EU legislation on novel food or the relaxing of the EU feed ban rules, constituted decisive factors which contributed to boost the advancement of the sector whilst creating the conditions for its steady development.